PRELIMINARY REPORT
ON
THE FEASIBILITY OF MOBILE SEA LAUNCH OF LARGE BOOSTERS

OCTOBER 1962

U.S. NAVY

BUREAU OF NAVAL WEAPONS

ASTRONAUTICS OFFICE

WASHINGTON 25, D.C.

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SUMMARY

This report submits findings on the over-all feasibility of placing military payloads into orbit from an Astronautics Launch Ship. Orbits of 100 mile altitude are of particular concern. Fully developed boosters and upper stages are shown to be satisfactory both as to payload capability and compatibility with the over-all system. Naval operations at sea are studied from the point-of-view of past and present success in mating major military gear to ships. The advantages of mobile launch are found to be numerous and include special orbits to overfly selected geography from various directions in a single pass. Payload advantages due to mobile launch are reported in numerical form. Guidance and control are studied--these results show no degradation in the essential accuracy that would make sea launch less feasible than land launch for the types of missions considered. Representative ship conversions are presented with their salient features and the major equipment and structure items to be included. Both stern mounted launchers for large liquid fuel boosters and tubes for cold launching of solid fuel boosters are included. Costs and time estimates are made for a number of conversions having different degrees of refinement and capacity and including the conversion of a large combatant hull. In assessing feasibility, all the essential subtasks of mobile launch are found to have been demonstrated and reliability and accuracy are estimated to stand at essentially current levels for land-based systems so that a positive feasibility conclusion is reached.

FIGURE INDEX

Figure Index -- Continued

SECTION I
GENERAL CHARACTER OF SHIP LAUNCH OPERATIONS

A. THE NATURE OF SHIP LAUNCH OPERATIONS

Through history sailors have managed, with considerable success, to take many land based systems weapons and methods to sea. While the sea environment imposed many problems such as confined space salt water corrosion and often times undesirable motion, these problems were generally solved to the point of creating useful operational systems. A few examples might be in order. Major calibre guns, through sixteen inch, were installed and stabilized in large ships with tactical capabilities which at times exceeded the capabilities of their land based counterparts. A wide variety of rocket propelled missiles have been installed and fired. These range from Tartar, Terrier, Talos, Regulus I and II and Polaris. On an experimental basis the V2, Argus and Viking were fired.

The problems addressed in this report involve adapting presently available large boosters to existing ships for the purpose of injecting useful military payloads into one hundred mile high single orbits. The usual constraints of space, the problems of position and motion and the over-all aspects of the sea environment must be overcome.

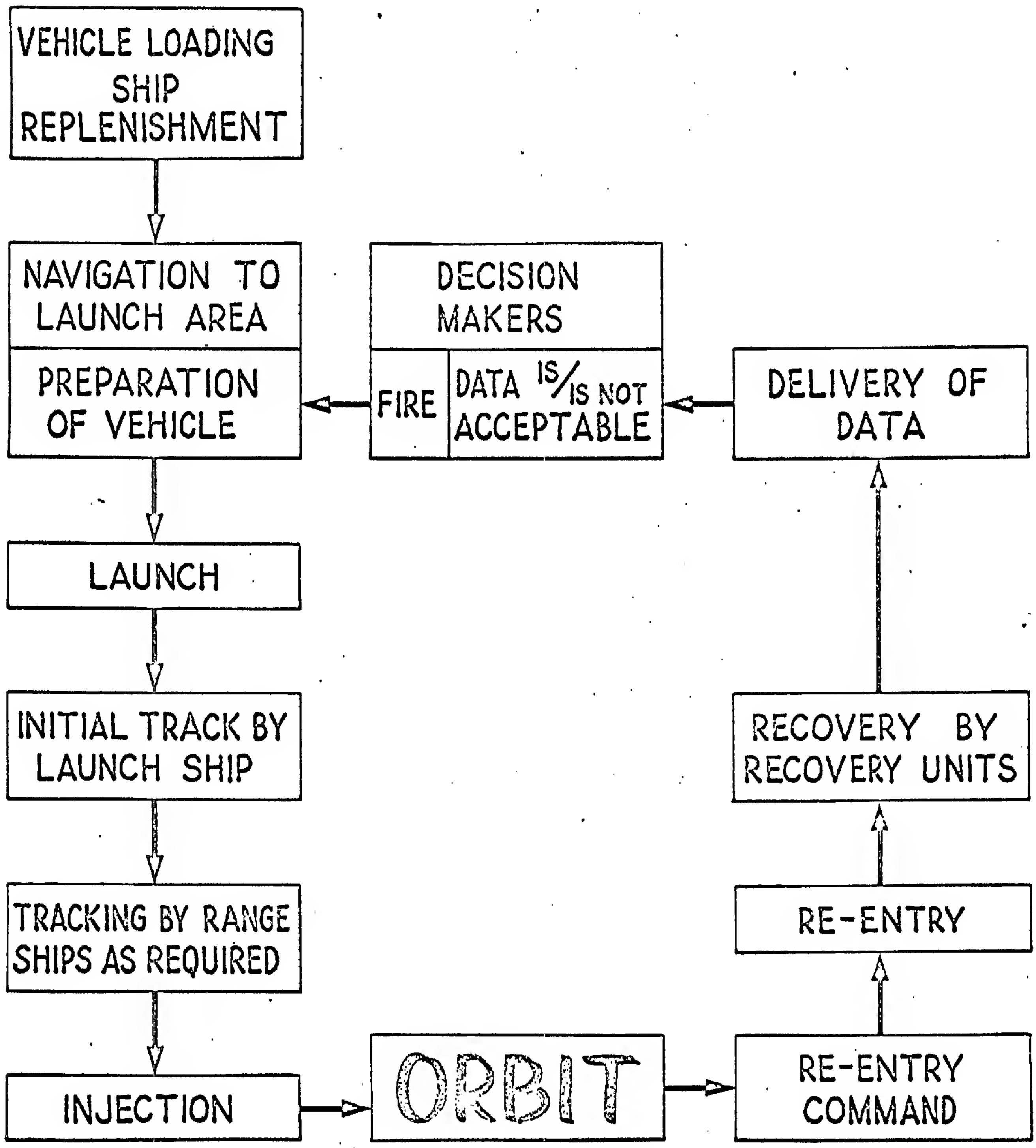
In whole or in part all of the facets of launching large boosters from ships have been experienced in the past years of naval technical development. The major problems would seem to be associated with accomplishing the necessary adaptations. These involve stabilized platforms for determining the local vertical and in turn ensuring that the resulting accuracy of orbit is within useful limits for the assigned mission. Certain conversions in selected ships will have to be made in order to accommodate the large boosters on the launch pad. The solid fueled boosters adapt the Polaris "cold shot" concept of tube launch. The liquid fueled boosters would be launched from pads on outriggers over the fan tail so that the rocket blast mainly impinges on the water. Limited stabilization will be required for the fan tail launching pad. Ships's stabilizers would also be used. Certain additional conversions are necessary for safety and for fuel handling. These too are mostly adaptations of well developed capabilities to new but related circumstances.

The existing technical competences coupled with the long established arts of seamanship and navigation would appear to indicate that all problems of adaptation and improvisation can be solved to the point of demonstrating a useful single orbit 100 nautical mile altitude military mission.

B. The Over-all Operation

All essential operations, and only those, for a mission which includes recovery are shown in the block diagram (Fig. I-1). It is noteworthy that the kinds of operations that show up in the diagram are typical of all naval operations.

SYSTEM BLOCK DIAGRAM

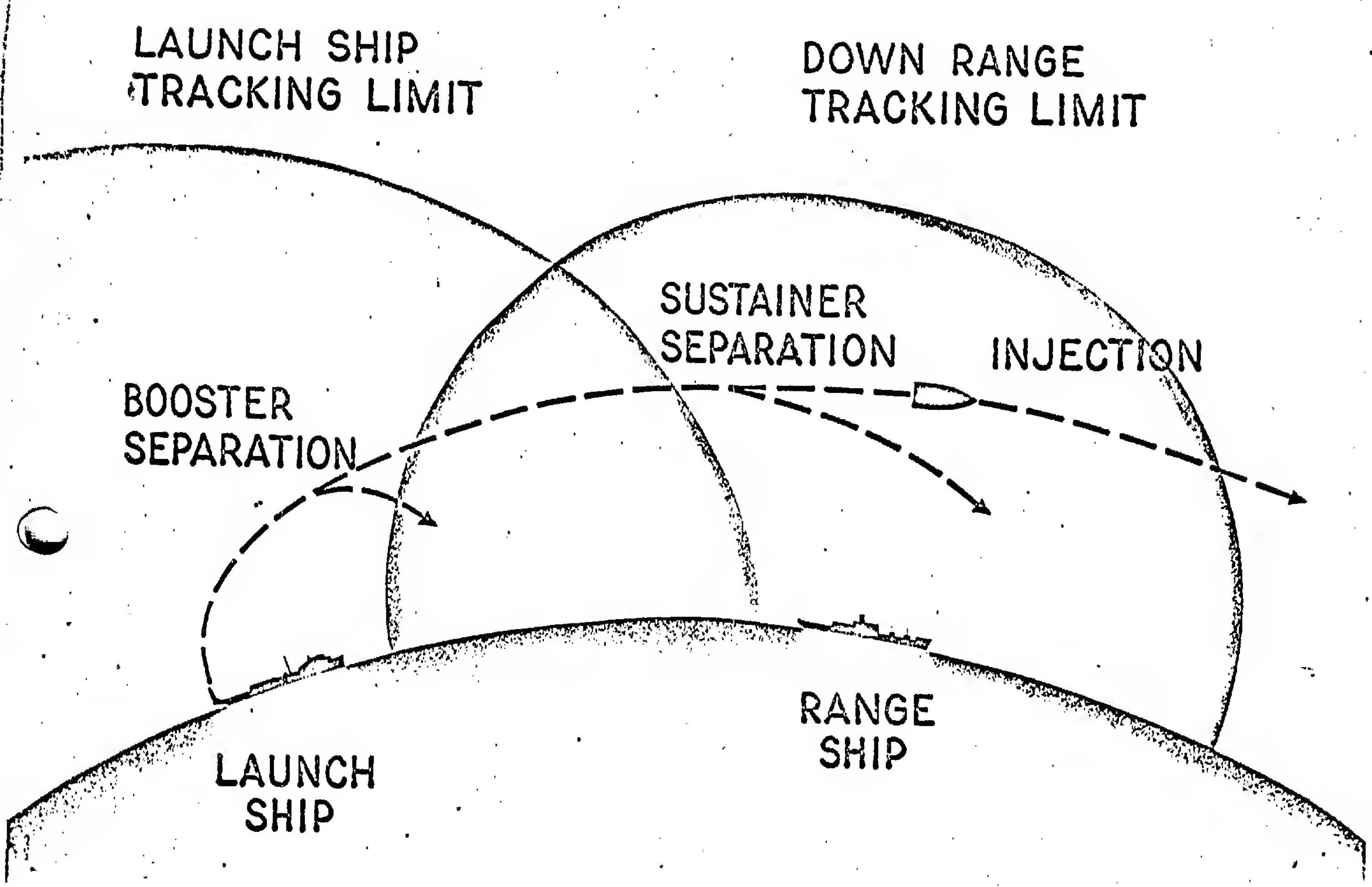


The command and control function is apparent in the "decision block" particularly and prevails throughout the operation. As part of a coordinated military operation, the launching would need to be timed and located in conformance with the over-all plan. Efficient communications facilitates this. Depending on the requirement of the mission, the launch ship might participate in recovery operations. It could be the means for commanding by radio the control events in the spacecraft which will initiate re-entry. It can be a unit of the recovery force.

Preparations for launching are performed aboard ship but are minimum as compared with the preparations which take place at a land-based launching site. This is made possible by rigidly adhering to acceptance procedures prior to loading launch vehicles and payloads aboard ship. The flight vehicles will be in a T-2 day condition at loading. Thus, the assembling of stages and meticulous checkout during assembly will all have been performed. A transporter-erector is mated to the flight vehicle to act as a strongback during all handling and loading operations. Environmental conditioning is provided for large liquid fueled vehicles in a hangar and for solid fueled vehicles in a launch tube. For the former the major items of checkout to be performed aboard ship are done with the flight vehicle horizontal. After mechanized transfer from the hangar to the stern launcher, final checkout is performed including fueling; control, propulsion, and payload systems final check; and separation of the strongback. For solid fuel launch a port in the launch tube provides access for checkout operations.

The ascent sequence is show in greater detail in Fig. I-2. For purposes of example, an Atlas/Agena-B vehicle would, after launch, go through the staging operations as shown. The booster section of

ASCENT SEQUENCE



the Atlas sustainer is jettisoned after it cuts off and then at burnout there is a second separation leaving the final stage, Agena-B, to attain orbital conditions. The latter, with its restart capability, permits powered and coasting flight in accordance with the requirements of optimizing payload-orbit relationships. Engine cutoff at orbital injection conditions is either on command from the ground or from on-board intelligence generated from inertial sensings.

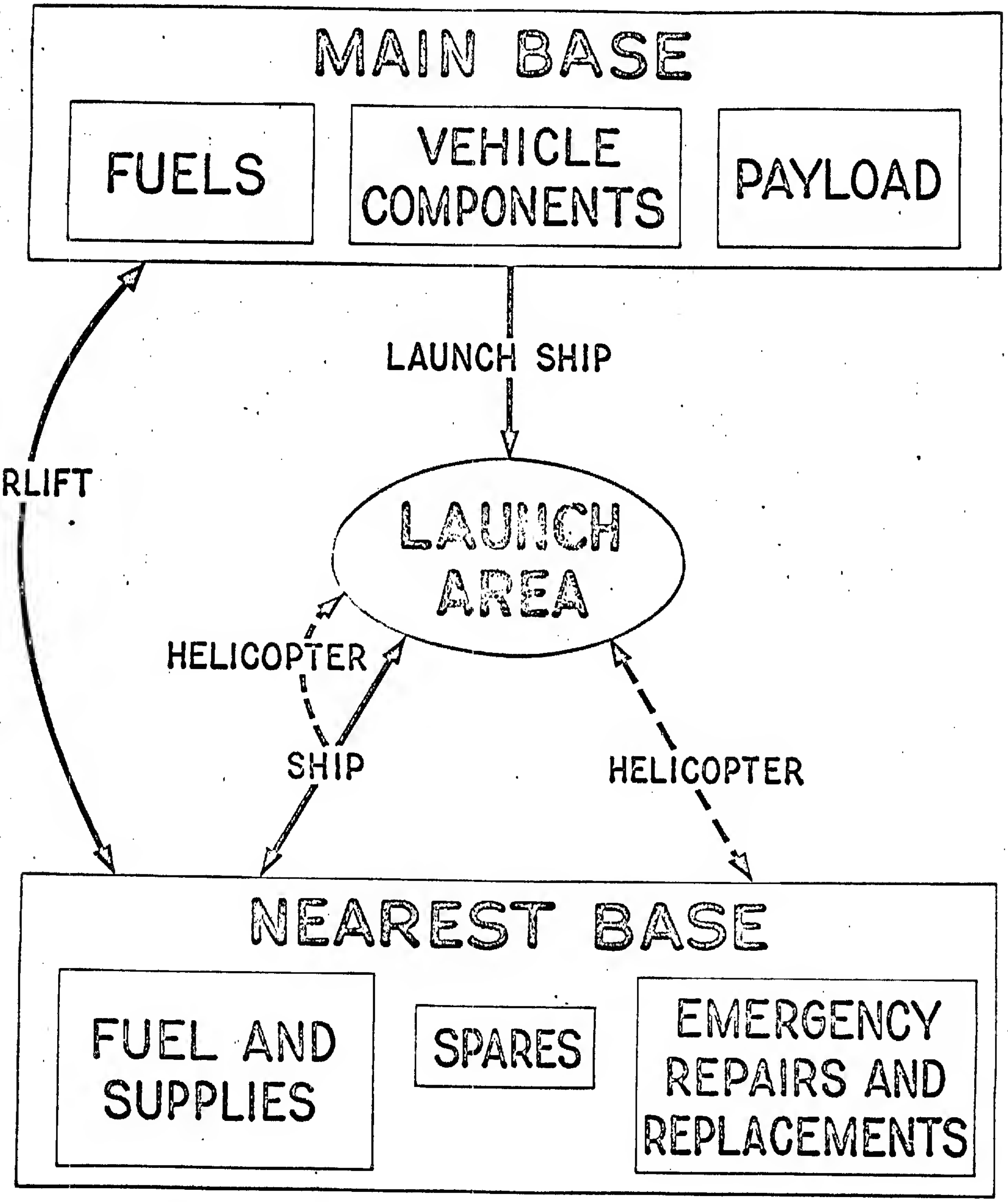
Tracking ships would be employed for particular missions as necessary. They can play a role in guidance and control of the launch vehicle where radio command systems are used, especially of the multiple antenna type. For any type of control it can be required that tracking is an essential for immediate confirmation of the orbit. Another function for tracking ships may be in conjunction with range safety.

Referring back to the block diagram it may be seen that the mission in question contains re-entry and recovery. This involves attitude control and firing of retro rockets at a position to give impact at a predetermined location. Recovery units include winged aircraft for both search and mid-air recovery and helicopters for recovery from the sea, all in conjunction with high speed naval units afloat.

C. LOGISTICS

The logistics of such an operation also involve adaptations and improvisations based on extensive previous experience. Planning and foresight loom importantly here. As shown in Fig. I-3, the ships would be loaded at one or more ports depending on the location of the

LOGISTIC FLOW DIAGRAM



several major items such as boosters, satellites, booster fuel and ship's fuel.

Because of the space limitations the boosters would be expected to be in the T minus 2 day condition. Final assembly and adjustments would be made enroute to the launch area. Minimum delays would be expected upon arrival. It would appear that at least three vehicles would be placed aboard. This will permit flexibility in event of technical difficulty or it would furnish a quick back-up mission if ordered.

Resupply and any necessary replenishment falls back on the normal logistics procedures. There will be a main base of operations in the Pacific, this might be a California port or Pearl Harbor. There will be a nearest base depending on the launch area. This could be one of a large number of island facilities such as Eniwetok, Kwajelein, Canton, Guam, Midway, etc. Combinations of replenishment ships, transport airplanes and helicopters will ensure a resupply service comparable to that achievable at a continental base.

SECTION II
ADVANTAGES OF MOBILE LAUNCH

A. ORBITAL CAPABILITIES

Mobile sea launch provides the capability to select at will a launching point from approximately 70% of the earth's surface. This is of particular importance in missions where a single orbital launch can be from the antipodal point with respect to an area being observed. In fact, any location on the track of a selected orbit will suffice.

On such missions there are two contributions to a covert operation if mobile launch is used. By gaining complete freedom in launch azimuth and by launching from the antipodal point of the target it is possible to select any great circle for the orbit so long as it contains the launch site and the target. Hence, the orbiting payload overflys the target from an unpredictable direction. This makes hostile detection much more difficult and reduces opportunities for hostile countermeasures. The other security aspect is that observers can be barred from the launch area. It is furthermore possible, when using a converted merchant ship, to employ camouflage measures to conceal the identity of a launching ship. The tube launch system as employed with solid fuel boosters is more conducive to this than is the stern launcher for large liquid

fuel boosters. The conduct of covert operations from fixed installations is deficient in all regards.

Other special orbits may also be obtained much more readily by selecting optimum launch location:

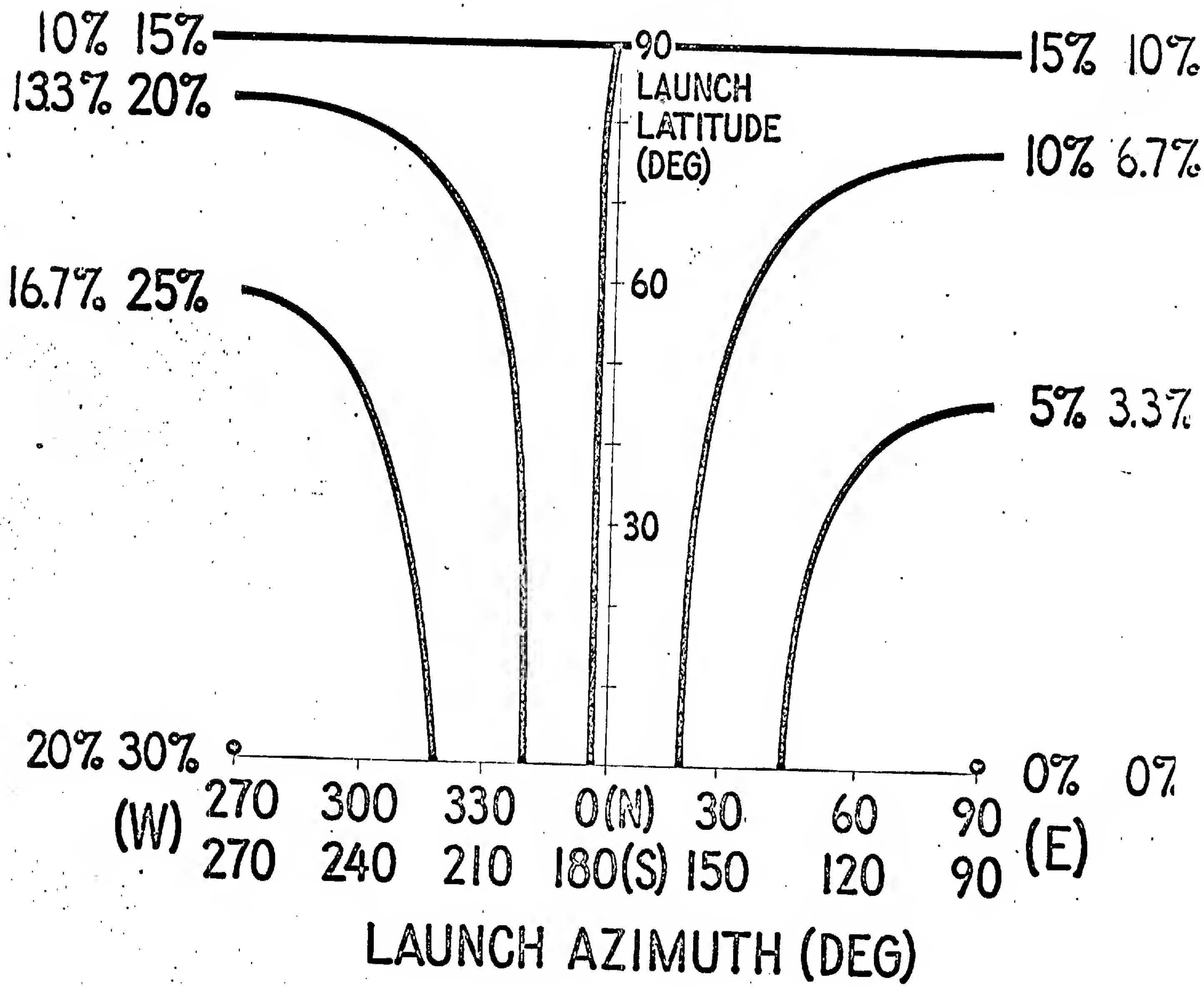
1. Single orbit for recovery in selected area.
2. Polar orbit.
3. Trajectory to avoid overflight of populated areas.
4. Trajectory to overfly existing range instrument.

B. PAYLOAD CONSIDERATIONS

By selecting a launching site on the equator and launching in an easterly direction, maximum advantage of earth's rotation is taken in placing a payload in orbit. For a specified launch vehicle, a fractional part of the payload capability is lost as the launch azimuth departs from 90° (easterly) and as the launch site departs from the equator. This penalty also varies with altitude of the orbit, being less for higher orbits. Typical results are plotted in Figure II-1 for a 100 nautical mile altitude circular orbit and values of final stage specific impulse of 265 and 425 to cover a range from solid fuel to the hydrogen system of Centaur. It may be seen that this penalty goes as high as 30%. For AMR the penalty for most of the launch azimuths would be between three and eight percent. The values are all on the basis of total weight in orbit. The percentage penalty in net payload will be higher; the

TOTAL PAYLOAD PENALTIES

FINAL STAGE SPECIFIC IMPULSE (TYPICAL) FROM 265 TO 425



actual value depends entirely on the structure factor or ratio of net useful payload weight to total weight for the final stage; typical current developments attain a factor of approximately 0.5.

There is also a performance penalty for turning the plane of an orbit either during boost or at injection in order to achieve an equatorial orbit from a non-equatorial launch site. This is the maneuver often referred to as the "dog-leg". The penalty is usually stated in terms of the velocity increment required of the propulsion system to perform the injection with a dog-leg as compared to a purely planar boost and injection. As in the case of the earth's rotation penalty, this one is also dependent on the altitude of the orbit and the structural ratio, and in addition the sequence of maneuvers influences the result. Typical results are tabulated as follows:

TABLE II - 1

Velocity Increment Comparison - Equatorial and AMR Launch

Orbital Altitude (N. Mi.)	100	300	300
Reqd. Circular Orbit Velocity (fps)	25,560	24,800	10,100
Velocity Increment (fps)	12,400	11,300	1,170
Earth rotation effect (fps)	180	180	180
Total velocity penalty (fps)	12,580	11,480	1,350
Penalty as percent of reqd. velocity	.49	.46	.13

In the case of higt titude orbits, the percent penalty would seem to be of less sign ance but this is a deceptive appearance since small penalties h have large consequences as the capabilities of even the larges unch vehicles need to be utilized to the limit.

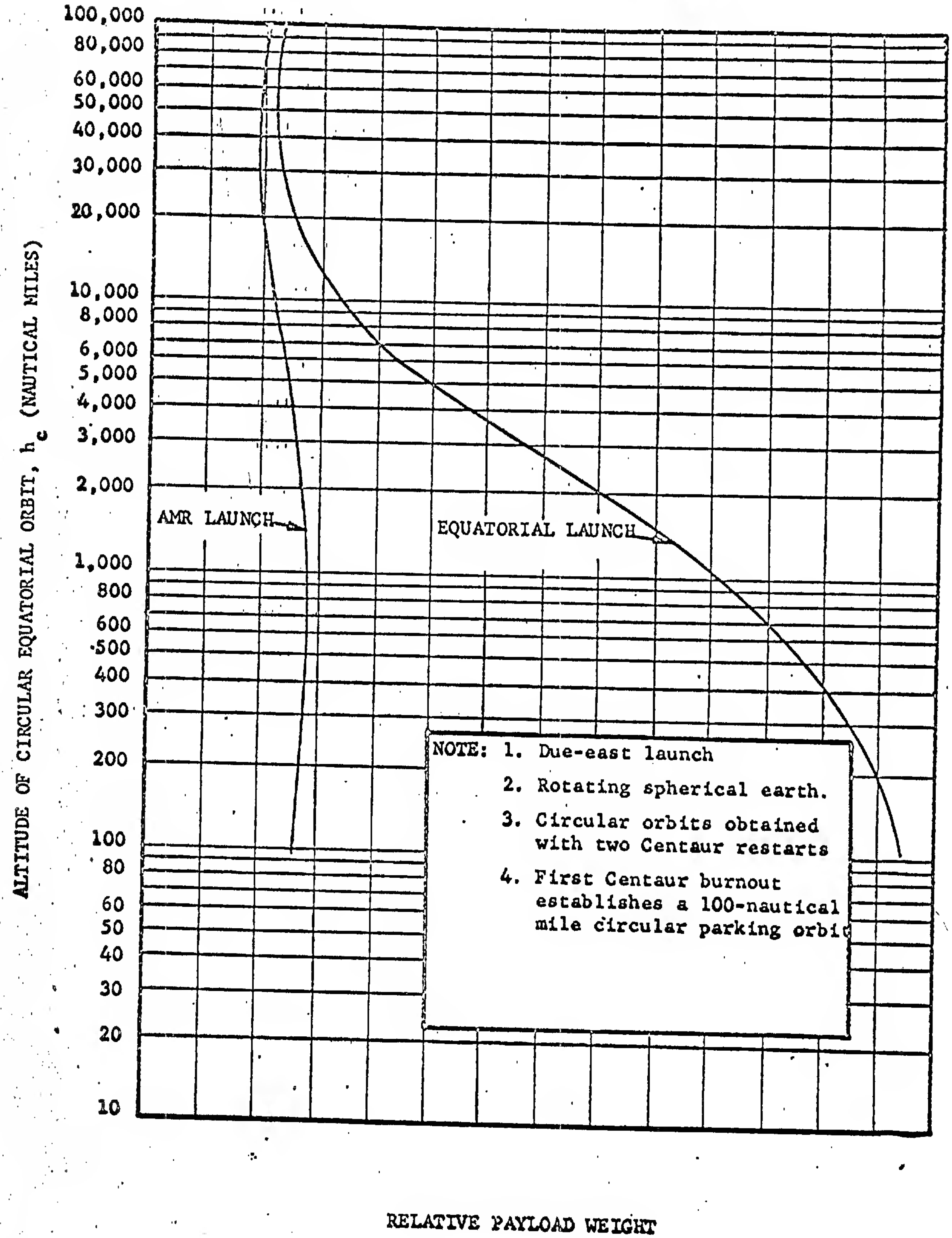
The veloci crement "dog-leg" maneuver can be reckoned als ad pc Figure II-2 there are results for a large l boos ry high specific impulse upper stage. For ni. circu bit the useful payload capability of the AN h is 20% of quatorial launch.

Conside of the sec of events for obtaining equatorial orbits il es the f simplification which may be obtained. On ne proc follows:

(1) ial low alt rcular orbit (100-200 n. mi.) ined, plan e launch point.

(2) lanar tran ipse is initiated with perigee initial alti d apogee at the desired end a de.

(3) gee of the al orbit an impulse is applied vert to a orbit, and for the case of the uatorial nt to turn the plane of the orb...


100,000
80,000
60,000
50,000
40,000
30,000
20,000
10,000
8,000
6,000
5,000
4,000
3,000
2,000
1,000
800
600
500
400
300
200
100
80
60
50
40
30
20
10
ALTITUDE OF CIRCULAR EQUATORIAL ORBIT, h_c (NAUTICAL MILES)
AMR LAUNCH
EQUATORIAL LAUNCH
NOTE: 1. Due-east launch
2. Rotating spherical earth.
3. Circular orbits obtained with two Centaur restarts
4. First Centaur burnout establishes a 100-nautical mile circular parking orbit
RELATIVE PAYLOAD WEIGHT

It is obvious that the thrust vector of the last impulse, most of which is expended in the direction changing (for low altitudes), must be controlled accurately in direction and also in time duration. An attitude control system would need a range of nearly 90^o and a longer period over which the control was maintained as compared to the case where no turning was required.

SECTION III
LAUNCH VEHICLES

A. AVAILABILITY CONSIDERATIONS

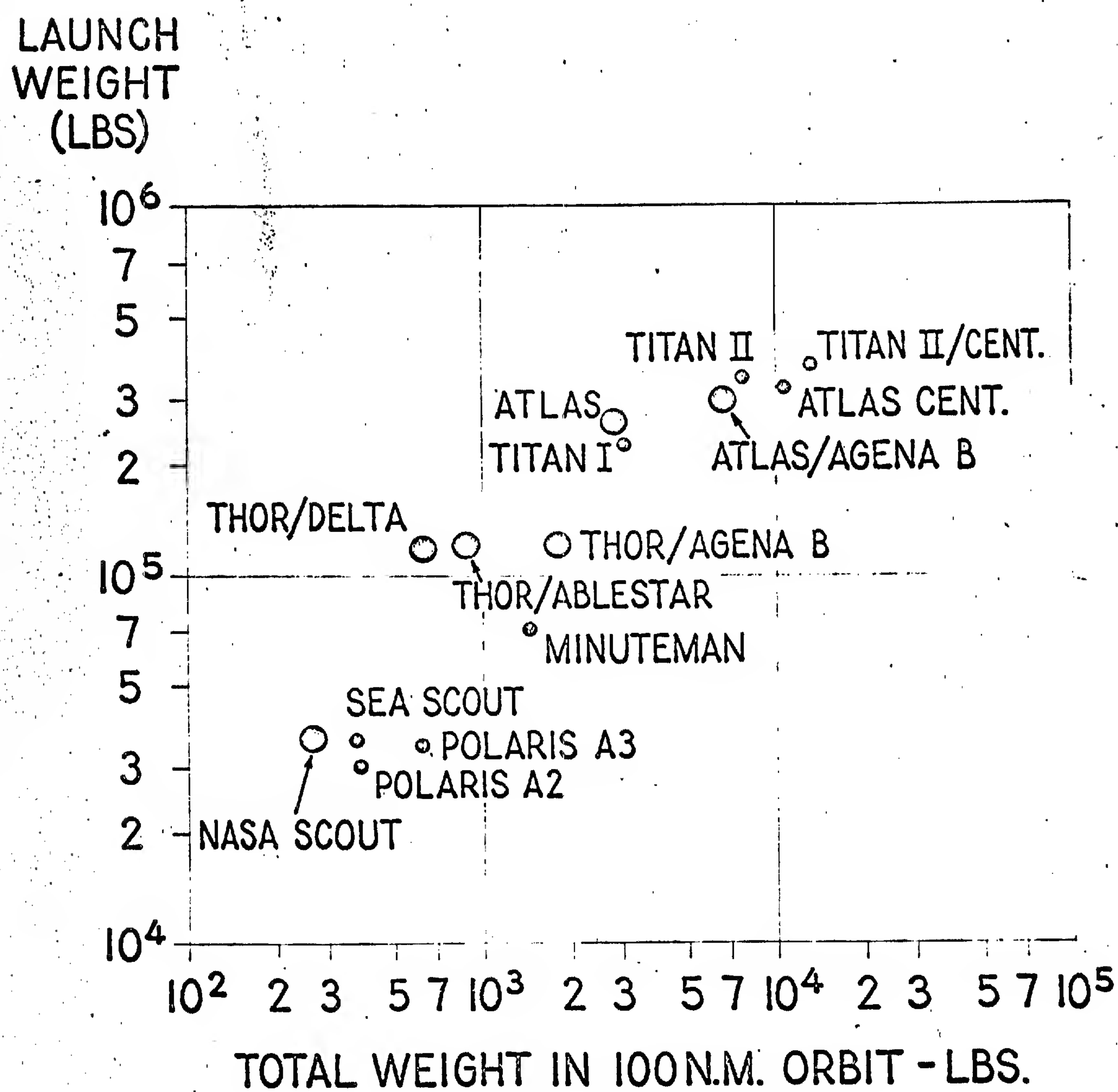
In order to provide a system with orbital capability quickly and with minimum cost, the use of existing equipments should be considered, wherever possible. Additional advantages accrue from this choice, as a result of operational experience with each system, namely developed payload compartments, established reliability, available maintenance experience, developed maintenance and checkout equipment, and satisfactory guidance, control and tracking equipment.

The vehicles considered in the study are primarily those currently in use to put payloads into orbit from PMR, AMR and Vandenberg AFB. In addition, those vehicles that are currently under active development or that require only payload package development are considered as potential launch vehicles for future ship launch systems.

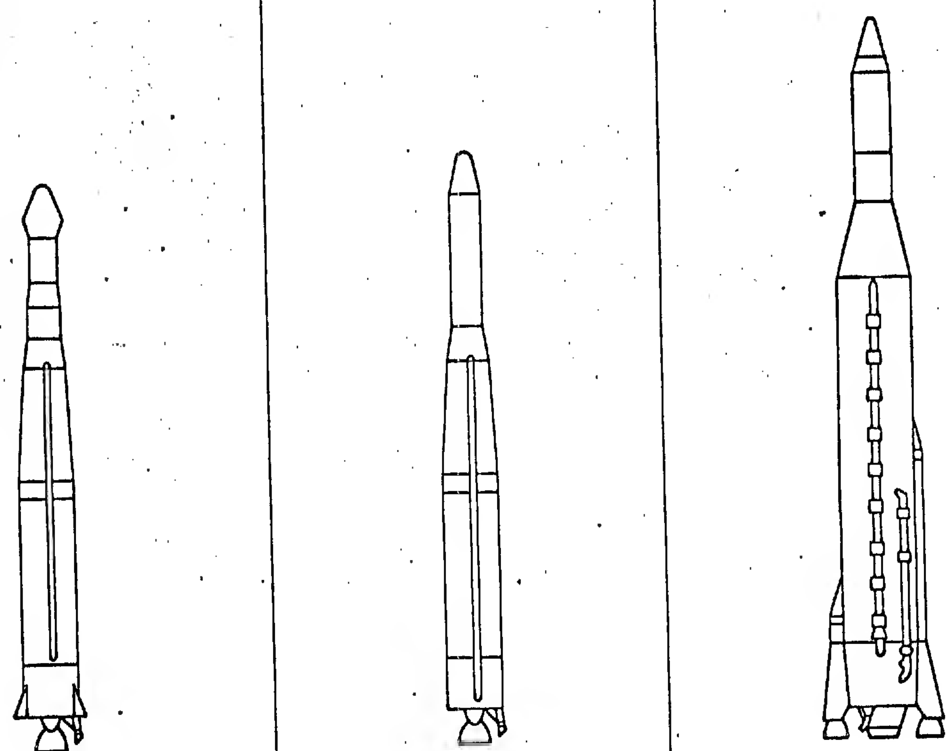
The approximate gross weight that each of these launch vehicles is capable of placing into 100 nautical mile orbit is shown on Figure III-1, and those vehicles that have a demonstrated orbital capability are high lighted. The particular vehicles that are recommended for almost immediate use in this operation, are the Thor-series, (including Thor-Delta, Thor-Ablestar and Thor Agena B,) and the Atlas Agena B, as shown in Figure III-2. All of these vehicles have

AVAILABLE BOOSTERS

○ DEMONSTRATED ORBITAL CAPABILITY



EXISTING SYSTEMS WITH DEMONSTRATED CAPABILITY



	THOR ABLESTAR	THOR AGENA B	ATLAS AGENA B
HEIGHT FT.	79.3	81.4	98.8
DIAM. FT.	8.0	8.0	10.0
LAUNCH WT. LBS.	119,000	123,000	290,000
STAGES	2	2	2

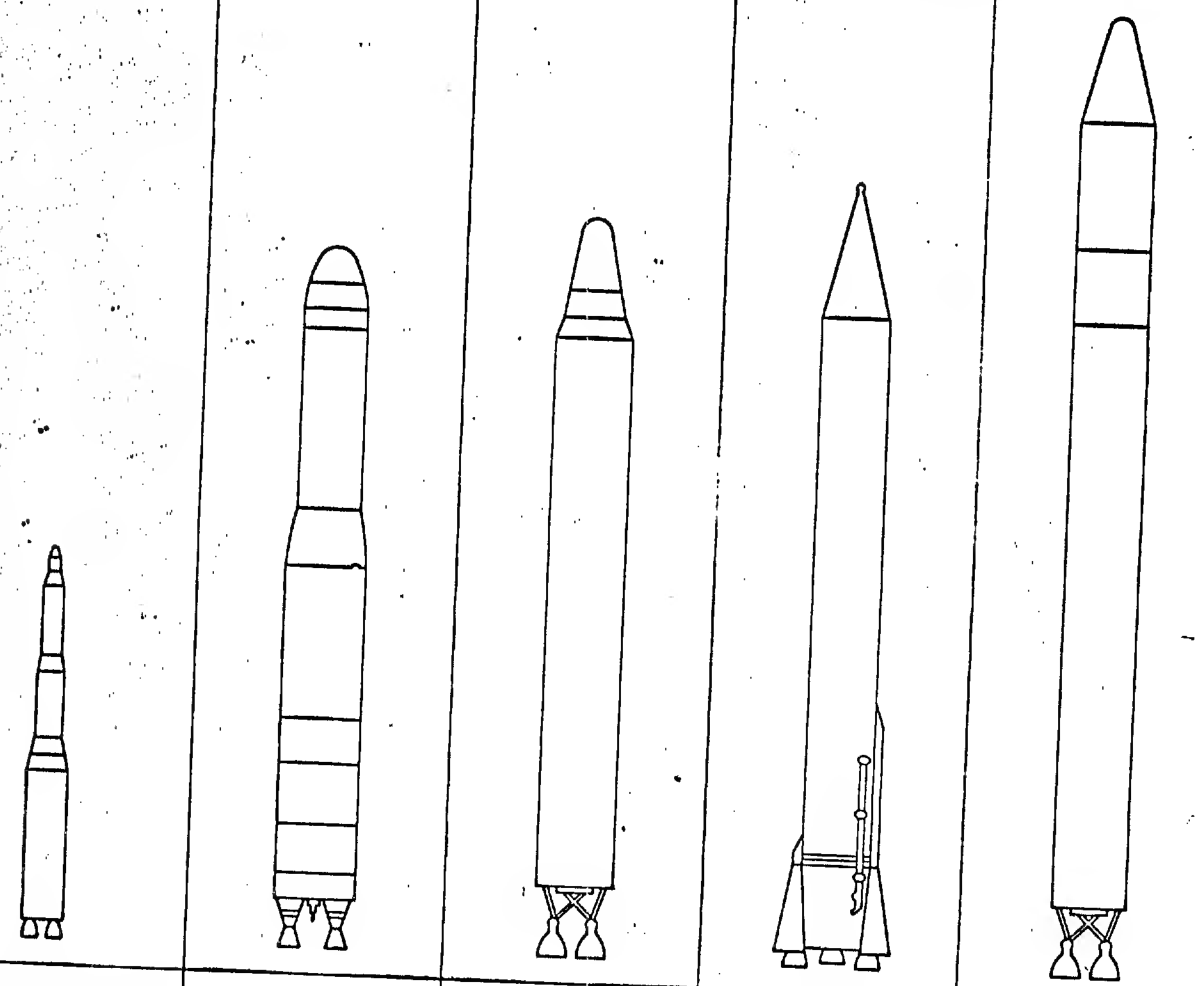
demonstrated their capability to place appreciable payloads into orbit with a high degree of reliability, all are well-established production items, for which proper operating and maintenance procedures have been established, and all are equipped to carry scientific payloads rather than warheads, the gross payload range in 100 nautical mile orbit covered by the group being from about 500 pounds to about 7000 pounds. In particular the Thor has been used many times with precision and with greater reliability than the other vehicles. Those vehicles that are considered appropriate for future development are shown in Figure III-3, and are Polaris, Minuteman, TitanI, Titan II, Atlas-Centaur and Titan II-Centaur. The first four are ballistic missile vehicles, and for missions of interest will require development of payload packages to replace warheads, while the remaining two are specifically under development for the national space program, and will accommodate scientific payloads.

B. ADAPTABILITY TO SHIP ENVIRONMENT

Vehicles for Immediate Use. The Thor series and the Atlas Agena series are all liquid-fuelled vehicles, so the first consideration is one of adequate and safe storage and handling of their fuels. The type of launch that can be best utilized in the ship environment is also fairly well determined for these vehicles; since the only valid experience that exists for Thor and Atlas series rockets is launch from an above ground pad, under rocket power all the way, such prospects as either "cold" or "hot" launch from silos, or cold launch from a pad, cannot readily be considered. The structural integrity of the vehicle must also be examined to ensure that the ship's motion will not endanger

FIG. III-3

FUTURE SYSTEMS REQUIRING FURTHER DEVELOPMENT



	MINUTEMAN	TITAN I	TITAN II	ATLAS CENTAUR	TITAN II CENTAUR
HEIGHT FT.	53.7	98	103	108	133
DIAM. FT.	6.2	10	10	10	10
LAUNCH WT. LBS.	65,000	220,000	330,000	295,000	350,000+
STAGES	3	2	2	$2\frac{1}{2}$	3

what is inherently a light-weight low-strength structure in bending when erected. Investigations have shown that the Thor has a good reserve of strength and can withstand ship's motion of $\pm$ 20° without any stabilized launch platform; the Atlas, on the other hand, has a thin-walled pressure-stabilized structure with limited bending strength, and requires the use of a launch platform stabilized to $\pm$ 1/4° of the horizontal. Launch vehicle maintenance and preparation is a complex procedure, and very time-consuming even with automation processes in use, and should be minimized. The concept of loading vehicles in the T-minus-2 day condition is to be recommended as it reduces the number of personnel and the amount of equipment required on board ship, and hence either reduces the required degree of ship modification or provides the potential for carrying more vehicles. The salt water environment must be borne in mind: easily removable plastic covers can protect the vehicle from any direct contact with spray. Great care must be taken to protect the electrical equipment from the prolonged effects of a salt-laden atmosphere; much experience has been already gained in this connection with the development of guided missile cruisers. The structure that will be required on board ship, as on land, for supporting the missile horizontally and vertically, must be stressed to account for ships motion and high winds at sea. Some modifications to the vehicles may specifically be required by virtue of the specific electronic equipment necessary for sea operations. For example, the identical radio-guidance equipment cannot be used at both PMR and AMR in land-based operations, and quite probably further changes would be necessary for ship launch.

SECTION IV
ORBIT ACCURACY ACHIEVABLE WITH SHIP LAUNCH

A. CRITICAL PORTION OF SYSTEM

The most critical part of the system, with regard to final accuracy in orbit is "injection", the accuracy of orbit depending entirely on the vehicle velocity, magnitude and direction, and the vehicle altitude, at the moment of injection or final thrust termination. All of the vehicle performance, from launch to final burnout, contributes to these final conditions, and a complete comparison can be drawn between accuracy on land and accuracy at sea by considering the land-based performance, and then by considering the perturbations introduced by the ship-board environment.

B. GUIDANCE SYSTEMS REVIEW

Fundamental to the whole question of vehicle trajectory is the question of vehicle guidance. The function of the vehicle guidance is to ensure that the vehicle is commanded to follow a flight path from the moment of launch that will bring it to the desired injection conditions within acceptable limits. The flight path may or may not be an ideal one--natural environments being what they are, it is extremely unlikely that a theoretical flight path will ever be completely followed so that guidance accuracy in part is determined by how well deviations from

the desired flight conditions can be detected, and corrected. The different guidance systems accomplish this in several distinctly different ways, as follows:

Fully Programmed Autopilot. In this system a three-axis autopilot is provided prior to launch with commands that are issued, as a function of time, to change orientation of the vehicle, with respect to the vertical reference to which the gyroscopes were set at the start of the flight. The path of the vehicle is completely determined by the initial conditions, the environment and the program, and once launched, no ground control is possible, other than destruction.

Radio-Guidance. In this case, the vehicle attitude is sensed by gyroscopes or horizon seekers but is controlled by ground commands. The vehicle is tracked using a special antenna system, and range, range rate and elevation information are used to compute present position and track, and desired future heading and attitude for correct burnout conditions. The vehicle path is therefore determined by reference to a ground-borne datum, and accurate control is possible.

Inertial. This system, like the autopilot system, is completely independent of ground commands. It measures instantaneous accelerations and attitudes, computes velocities and distances travelled, and then derives control commands for the desired future course. Its accuracy is dependent on the initial conditions set in, and the instrument accuracy and drift rates.

Radio-Inertial. A combination of radio data input and inertial data input provides, via smoothing technique, very accurate velocity

data for computation of the vehicle's flight path, with considerable improvement in accuracy over the pure radio system.

These systems are all subject to instrument errors, gyro drift and so-on, so that each one has an expected variation about the desired flight path that is characteristic of the system.

C. ACCURACY OF SHIPBORNE OPERATIONS

The potential accuracy of shipborne operations can be demonstrated by reference to actual operational equipment in use today, supported by a number of analytical studies.

Of great significance, because of the demonstrated capability that is apparent, is a comparison between guidance systems of the same type, on land and at sea, and the influence of their difference in accuracy on the injection parameters, and consequently on the orbital parameters.

Apart from the changes in the natural flight environment due to operating over water rather than land, changes common to all of the systems that are introduced by shipborne operations are those in the datum conditions existing at the launch point. These datum conditions are position, azimuth, velocity and vertical reference. The flight path from launch is directly related to the accuracy with which they are determined. Additional errors are introduced resulting from the effect of ship's motion, for some systems such as radio-guidance.

By comparing current equipment, such as is available on board the Polaris-firing submarines, with current land-based inertial systems, the difference between land and sea datum accuracies that is obtained is shown in Table IV-1. In addition to these degradations, the radio systems utilize an antenna which is slaved to the local vertical, (as measured by a servo-operated stable platform on board ship) which introduces some further angular error. These are the only factors that introduce any significant difference in the accuracy achievable from land and from sea.

The implications of the datum accuracy changes are simply expressed in terms of their effect on orbit injection parameters, and in turn the changes in orbit injection parameters are reflected in changes in the orbital parameters. These are shown in Tables IV-2 and IV-3 in which the difference due to initial errors are illustrated.

TABLE IV-1
Initial Errors

	Land	Sea
Position - Feet	0	600
Vertical - Arcsecs.	5-10	30
Azimuth - Arcsecs.	10-20	60
Velocity - Feet/sec.	0	.8-1.6

TABLE IV-2
Difference Between Injection Errors, (Sea Minus Land)
For 100 Nautical Mile Circular Orbit

Altitude - Feet	60	to	120
Velocity - Feet/sec.	.8	to	1.6
Flight Path Angle - Degrees	.06	to	.07
Inclination - Degrees	.11	to	.14
Position - Feet	660	to	670

TABLE IV-3
Differential Orbital Parameter Errors

Major Axis - Feet	160	to	320
Eccentricity	.00003	to	.00006
Inclination - Degrees	.11	to	.14

These figures indicate the comparative errors that would be inherent due to launching a payload from sea rather than land. Developments in equipment and new techniques in measurement will reduce these appreciably; the expected sea and land errors by 1965 are shown in Table IV-4. It is clear that those systems that depend purely on initial data for their basic input will suffer practically no degradation in accuracy as a result of sea launch.

TABLE IV-4
Initial Errors - 1965

	Land	Sea
Position - Feet	0	600
Vertical - Arcsecs	5-10	20
Azimuth - Arcsecs	10-20	15
Velocity - Arcsecs	0	.35

The remaining systems, primarily those utilizing radio-guidance, will suffer some loss in accuracy due to the need to transfer tracking data through the medium of an antenna which has to be designed and powered to overcome the effects of ships motion. An assessment of the accuracy of several different systems, all applied to the Thor-Ablestar vehicle, is shown in Figure IV-1, and indicates the small error introduced by ship launch, even with current equipment and minimum stabilization. The first two systems make use of a simple ship-borne stable platform which is only accurate to $\pm$ 1 1/4° in the vertical direction, and yet 99% of the resulting orbits will have an increase in error of no more than 1.67% over the land-launch case. The equipment most widely used for this vehicle is the radio-guidance single antenna; this uses an antenna which is stabilized to counteract ship's motion slaved to a highly accurate, stable platform. This results in a lower degradation than for the fully programmed autopilot case. Note that in this assessment the assumed stabilization equipment is less accurate than might be expected by at least a factor of 2. The inertial guidance cases also assume stable platform accuracies that are conservatively rated, again showing that the changes due to sea launch can be appreciably less than indicated.

GUIDANCE ACCURACY

THOR-ABLESTAR (WITH OPEN LOOP CONTROL AT INJECTION)

SYSTEM	ACCURACY OF VERTICAL IN SHIP	3σ (APOGEE-PERIGEE) VALUES FOR 900 NM ORBIT		DIFFERENCE	ERROR (% ORBIT ALTITUDE)
		SEA	LAND		
FULLY PROGRAMMED AUTOPILOT	$\pm 1\frac{1}{4}°$	300	270	30	± 1.67
SAME, WITH DELTA SYSTEM IN THOR	$\pm 1\frac{1}{4}°$	200	170	30	± 1.67
RADIO GUIDANCE SINGLE-ANTENNA (BTL)	± 1° (EST.)	190	166 (EST.)	24 (EST.)	± 1.33
INERTIAL	$< \pm \frac{1}{4}°$	162	156	6	± .33
INERTIAL THROUGH INJECTION	$< \pm \frac{1}{4}°$	20	14	6	± .33

SECTION V
SHIPS AS MOBILE LAUNCHING PLATFORMS

A. SHIP CAPABILITIES PERTINENT TO MOBILE LAUNCH

All the favorable attributes of mobile launching system are related to the capabilities of ships of the Navy. On a global basis, ships have superior mobility; they can traverse more than 70 percent of the earth's surface. Ships can handle loads and employ support gear which is greater in size, weight, and capacity than that available to mobile land operations. Ships are self-contained operational units which can remain at sea for extended periods.

There are two approaches for developing an astronautics ship for mobile launching: (a) design and build a ship from the keel up for this specific function, and (b) convert an existing hull to the degree required for the function. The spread of characteristics in existing hulls is so broad as to indicate that the desired qualities can be found. A representative listing is contained in Table V-1 below. Victory hulls (VC-2) (approximately 6,000 tons displacement) are considered to be inadequate as to space and are not included. Speed and displacement data are summarized graphically in Figure V-1. Pictorial representations

Table V-1

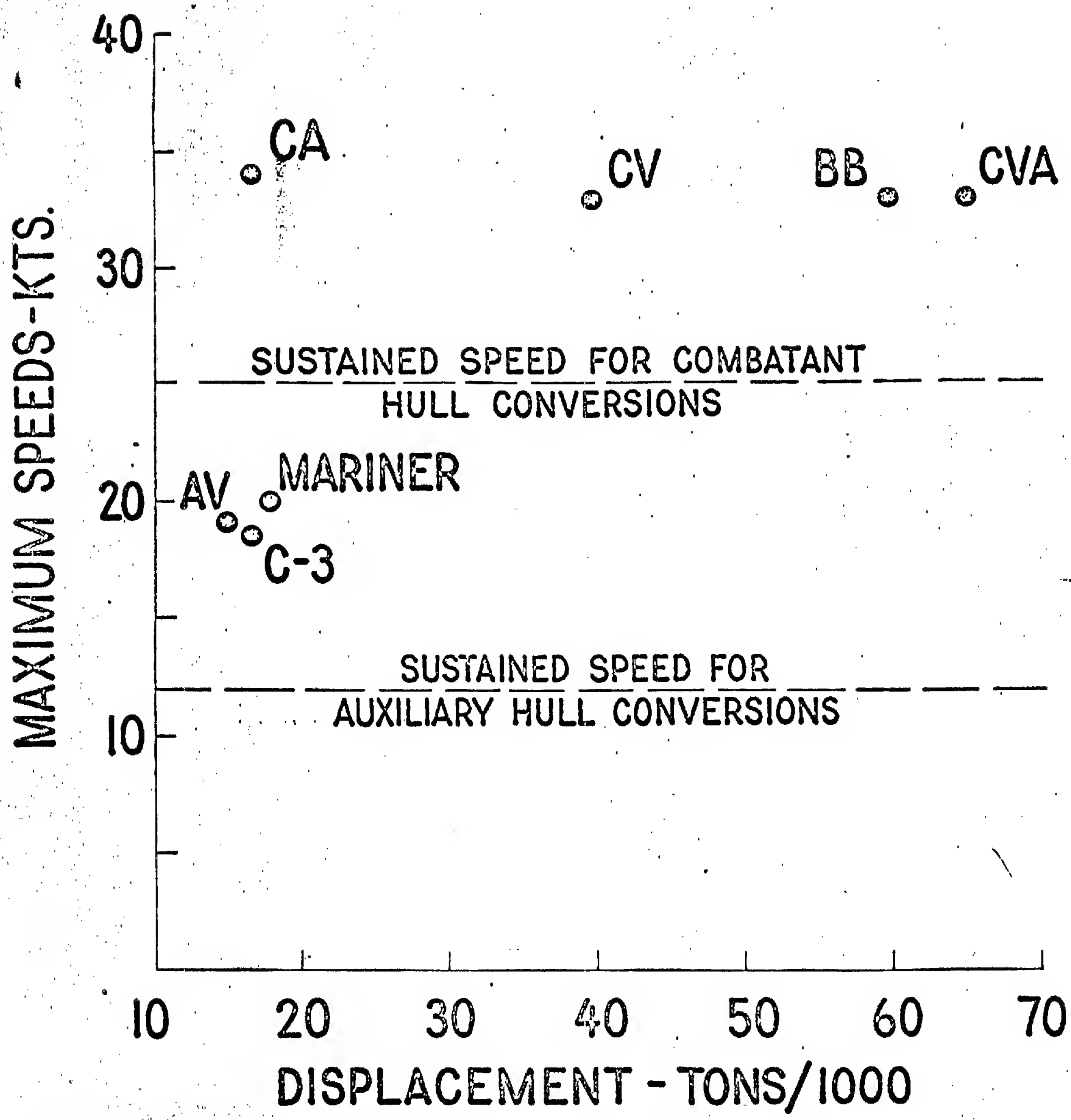
Naval Hull Characteristics

	(full load) Tons	Length Feet	Beam Feet	Power H. P.	Speed Knots	Complement (1)
Carrier (Midway Class)	62,000	974	113	212,000	33	$2,604^{+}$
Carrier (Essex Class)	38,500	786	93	150,000	33	$1,300^{+}$
Battleship (Iowa Class)	57,950	888	108	212,000	33	2,000
Cruiser (Baltimore Class)	17,200	673	71	120,000	34	1,400
Missile Ship (AVM1)	15,100	540	69	12,000	19.2	555
Seaplane Tender (AV4)	13,500	527	69	12,000	19.7	550
Mariner - C4-S-1	18,000	563	76	19,250	20	400^{-}
Mariner - (EAG 153 Compass Island) -- has activated fins-rolls 1.5° vs. 15° for sisters.						
Mariner - (EAG 154 Observation Is.) -- has two launch tubes, fired first Polaris						
AKA - C3-S-A2	16,000	492	69	8,500	18.5	250

Notes: (1) Complements indicated are peace time levels. + indicates that air group personnel are not included, - indicates that the number could be less for some functions.

SHIP SUMMARY

SPEED vs SIZE



of a converted Mariner for launching large liquid fuel boosters, and a converted C-3 for launching solid fuel are shown in Figs. V- 2 and V-3 respectively. Two of the more appropriate combatant hulls are shown in Fig. V-4.

B. HULL SELECTION

If a particular capability is hypothesized--say three launch vehicles in the Atlas/Agena B Class--and if, furthermore, budgetary limitations are overriding, then hull selection is straightforward and a Mariner as shown in the illustration is selected. Space is adequate for a minimum hangar, the overhung stern launcher can be accommodated, personnel safety is provided in the forward block house, speed/endurance are in line with other auxilliary units, and operating costs are minimum. For solid fuel launches with a more compact vehicle--say Minuteman or Polaris A-3 and assuming an appropriate final stage to be available--the boosters can be stowed vertically and cold-launched. In this case a smaller hull will suffice, the C-3-S-A2.

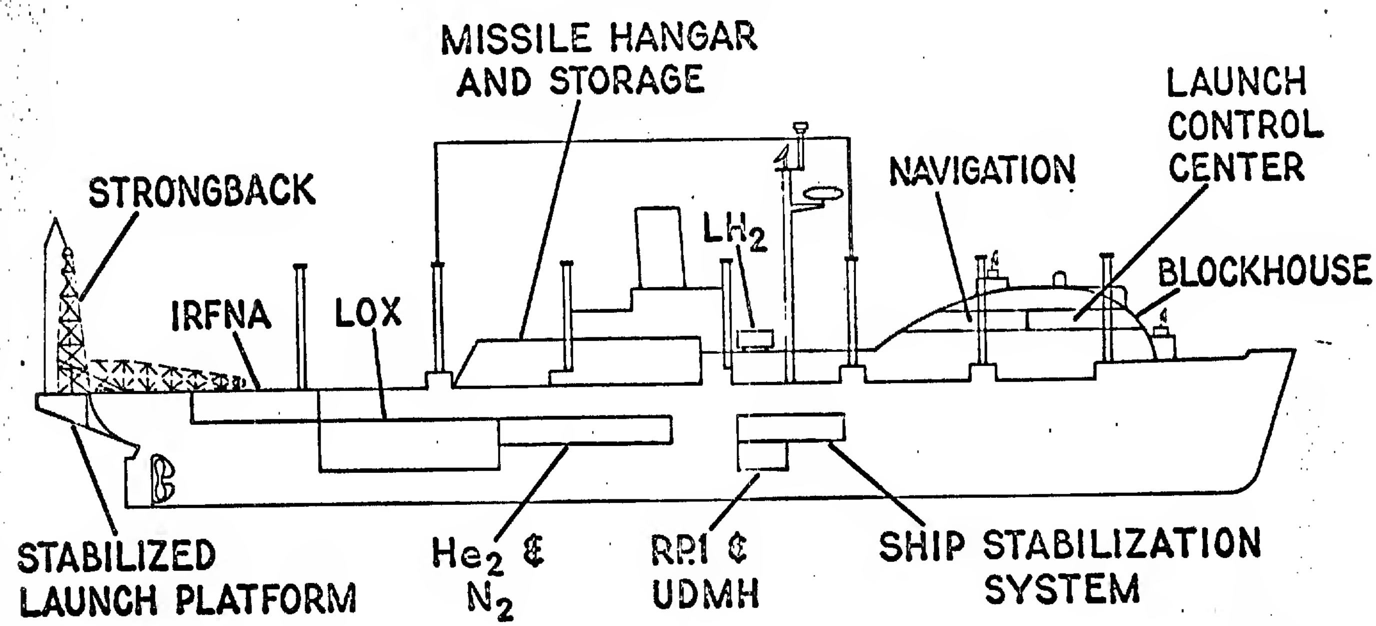
It is suggested in this report that full consideration be given to selection of a combatant hull. These qualities would be gained:

(1) High speed and greater endurance,
(2) Improved "sea kindliness" during launch operation,
(3) Greater deck and bulkhead strength for load carrying and safety,
(4) More space to receive succeeding generations of launch vehicles and/or increase numbers carried,
(5) Availability for recommissioning--particularly applicable to a battleship of the Iowa Class.

TYPICAL SHIP CONVERSION
"LIQUID" BOOSTERS

DISPLACEMENT TONS	LENGTH FT.	BEAM FT.	POWER H.P.	SPEED KTS.
18,000	563	76	19,250	20

ENDURANCE - 10,000 MI. AT 12 KNOTS

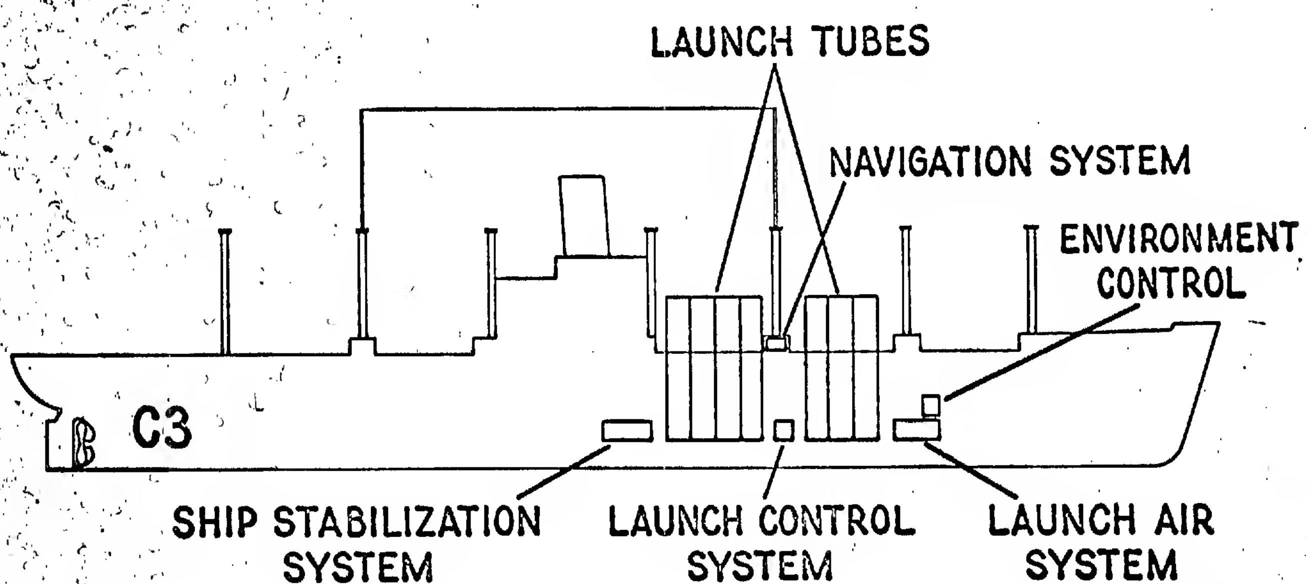


MISSILES	$	MONTHS
3 ATLAS	84 MILLION	48

TYPICAL SHIP CONVERSION
"SOLID" BOOSTERS

DISPLACEMENT TONS	LENGTH FT.	BEAM FT.	POWER H.P.	SPEED KTS.
16,000	492	69	8500	18.5

ENDURANCE - 10,000 MI. AT 12 KNOTS



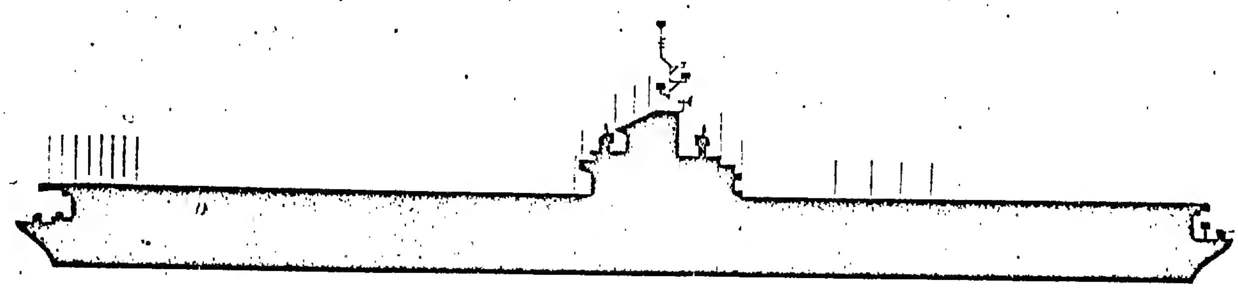
MISSILES	$	MONTHS
12 MINUTEMEN	50 MILLION	24

HIGH SPEED SHIPS

CARRIER — ESSEX CLASS

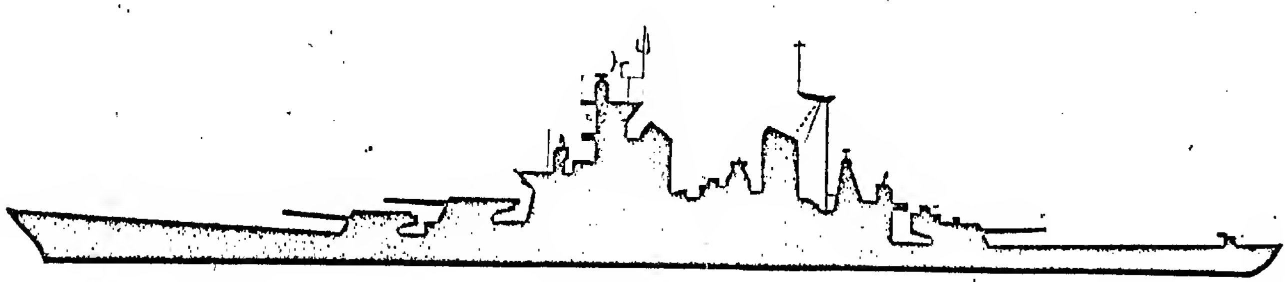
DISPLACEMENT	LENGTH	BEAM	POWER INSTALLED	SPEED	COMPLEMENT
38,500 TONS	786 FT.	93 FT.	150,000 HP.	33 KTS.	1300 (NO AIR GROUP ABOARD)

ENDURANCE - 6,000 MI. AT 25.2 KNOTS



BATTLESHIP - IOWA CLASS

DISPLACEMENT	LENGTH	BEAM	POWER INSTALLED	SPEED	COMPLEMENT
57,950 TONS	888 FT.	108 FT.	212,000 HP.	33 KTS.	2000



In the summary data on costs versus capabilities (Section VI) a wide spectrum is presented. It starts with a minimum conversion capable of launching a Thor vehicle and employing much of the existing mobile support gear. At the other extreme is the high speed, high capacity combatant hull with a complement of the most potent launch vehicles. A hull selection must be viewed in the context of the capability to be purchased with the available funds.

C. SHIP CONVERSIONS AND FACILITIES TO BE PROVIDED

The AGSL based on the conversion of a Mariner hull (refer to Fig. V-2) and equipped for the launching of large liquid fuel boosters will be considered here in more detail. Other conversions for liquid fuel vehicles would have most of the features in common with this conversion.

A stabilized launch platform is mounted on heavy structure overhanging the stern. This location is selected so that flame is dispersed over the surface of the sea and no blast deflector is required. In case of a malfunctioning booster, jettison into the sea is possible. The inability of Atlas to resist ship motions once its strongback is removed necessitates the stabilization mechanism (to $\pm$ 1/4°).

Handling and erection space is provided on the deck just forward of the launcher. Movement between the hangar and launcher is on rails. An erector mechanism is hydraulically actuated. An umbilical tower handles fueling and final checkout connections to the launch vehicle. Provisions for rapid washoff of fuel spillage include high camber on the deck and high water flow rates. The deck in this area is strengthened to take the concentrated loads of all handling operations.

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A hanger is large enough to stow, checkout, and service the three boosters of the Atlas class with their upper stage and payload. The maintenance concept does not provide for servicing comparable to that at land bases but major components and stages can be changed with the handling equipment provided. The hangar structure is designed with adequate strength to protect the launch vehicles from catastrophic explosions, even though it becomes deformed. Environmental control is maintained in the hanger, humidity, free from contamination, and vibration isolation as required.

Stowage tanks have adequate fuel capacity for all three launch vehicles. The illustration shows locations for all tankage required by boosters and upper stages. Liquid helium, as would be needed if Centaur were included, is in tanks on the upper deck. Boiloff from cryogenic fuels is captured, reliquified, and returned to the tanks but there are no facilities on board for bulk production of propellants.

Launch control, tracking, and ship's navigation take place in a forward superstructure which is highly blast resistant. Noise is attenuated within this area to acceptable levels (110 db.). Since all personnel will be in the forward part of the ship, facilities are included in the protected superstructure for remote engine operation. Closed circuit television gives observation of launch operations.

Instrumentation is provided to include these principal items: tracking radar, telemetry, command and control with a minimum function of self-destruct, navigation and timing system, communications, meterology, search radar, data display and other equipment which is normally located on naval ships.

A stabilizing system would consist of passive means for simplicity. 4600 tons of high density ballast in the lower levels will produce satisfactory draft and roll stability.

The salient feature of the conversion of a ship (Fig. V-3) for launching of Minuteman powered vehicles is the disposition of the launch tubes. In the illustrated design 12 launch tubes are installed in holds Nos. 3 and 4 of a converted Maritime Administration C-3 hull, just ahead of the deck house. Space in the after holds provides accommodations for the additional crew. The equipment for powering the ejection from the tubes and for conditioning the environment within the tubes is nearby the missile installation. Polaris techniques are completely applicable. Launch tubes are hinged and positioned at 7° off the vertical at launch to improve safety in the event of a failure to ignite--this is a very remote reliability hazard. The positioning of the tubes near the center of pitch and roll minimizes the effect of ship's motion. A passive tank device is included to further improve the roll characteristics. The active system employing controllable fins (demonstrated so strikingly on U.S.S. Compass Island) is not necessary.

Use of the ship system for Polaris is even more straightforward. The missile was designed from its inception for this kind of launch and few guidance changes are involved.

D. SHIP STABILIZATION AND NAVIGATION

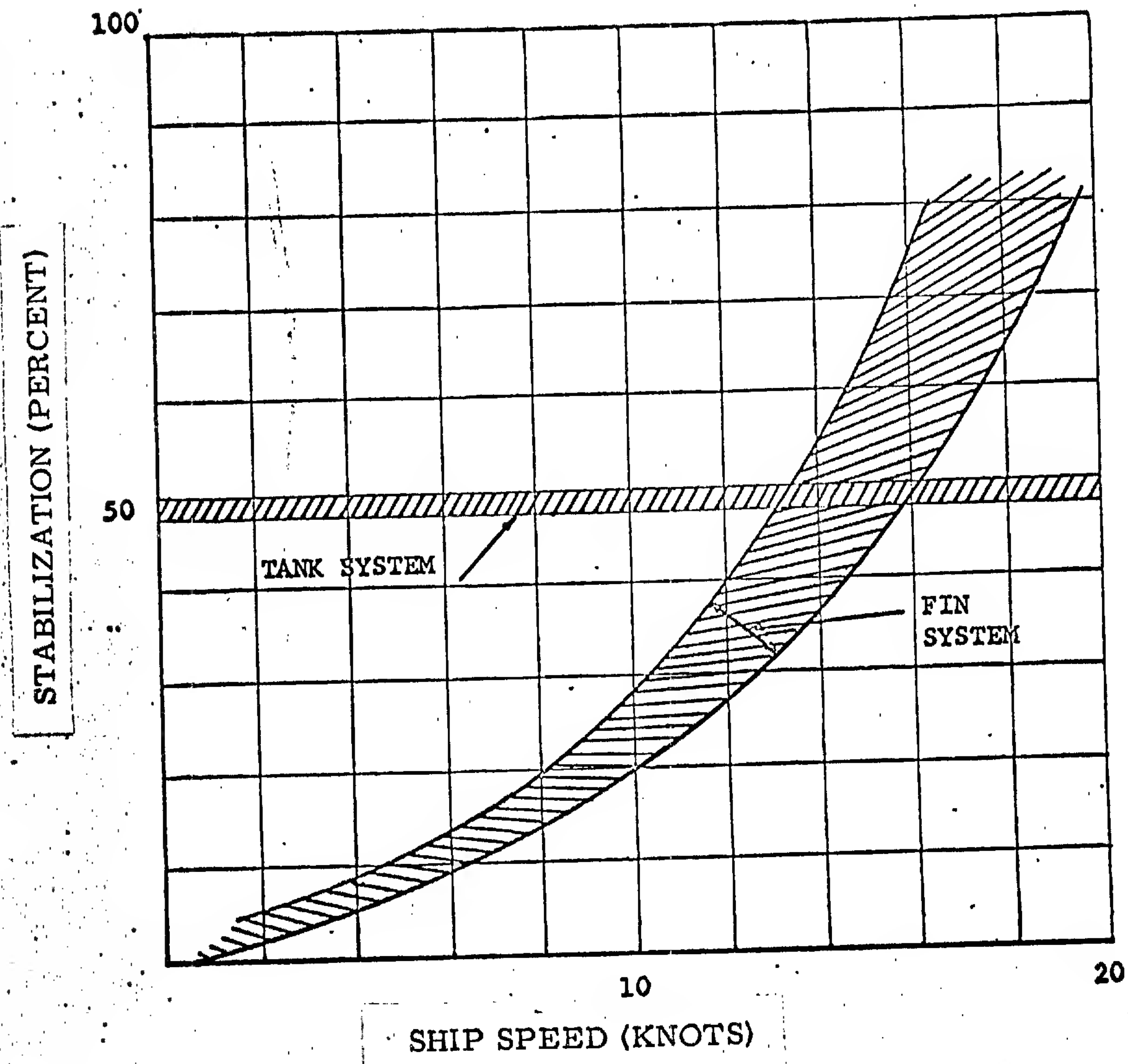
If the ship launch operations are to be effective from a military viewpoint then adverse weather conditions must be included as a design

criterion. Estimates coming out of all the feasibility studies indicate that Sea State 3 can be coped with. This is a generally moderate sea but with some waves as high as 12 feet. Sea State 4 operations are rated as feasible for only part of the time for open deck operations since wave heights can be much higher and considerable wind driven spray would be encountered.

Ship motions can be reduced by application of proven methods (Fig. V-5). To reduce roll excursions either fin stabilizers or passive tanks can be used. The fins are effective in proportion to the ships speed reaching about 80 per cent stabilization at 18 knots; at 15 knots there is 50 per cent stabilization. The tank method gives about 50 per cent stabilization regardless of ship speed. Therefore at all launchings from ships at speeds under 15 knots the tank system is more effective. Since wind loads must be kept low in the period when the strongback is off the booster, and there may be a heading into the wind, it is apparent that speeds lower than 15 knots may be used. The passive system is selected on this basis.

To show how a set of launching conditions effects the Atlas booster the following typical figures are supplied:

Sea State	3
Wind	15 Knots
Waves	10 ft (peak to trough)
Wave encounter period	4.5 sec (at 6 knot ship speed)
Base moment (pitch)	940,000 in lbs.
Base movement (wind)	260,000 in lbs.
Total base moment	1,117,000 in lbs.
Allowed base moment	4,000,000 in lbs.



SHIP STABILIZATION

The safety margin is ample. Careful ship navigation can further reduce wind velocity over the missile and pitching motions of the hull so that a selection of numbers from statistical sea descriptions is not conclusive. The indications are that, with discretion, launching operations could take place under many of the conditions prevailing during Sea State 4.

In the study of guidance and control accuracy (Section IV) it was apparent that ship navigation played a part. For the utmost precision within the state-of-the-art a multiple capability is to be provided consisting of:

Ships Inertial Navigation System (SINS)
Star tracker - N7D
Loran A and Loran C navigation receivers
Transit satellite navigation equipment
Omega VLF navigation equipment

E. SAFETY

The system design includes many measures to make the safety of personnel and material the highest order. No conflicts between safety and operating characteristics have been disclosed. The following are the specific measures:

(1) Capability to jettison the launch vehicle into the sea if malfunctioning indicates potential explosion,

(2) Dispersal of fuel tanks,

(3) Blast resistant bulkhead to confine major damage to stern area in case of catastrophe,

(4) Blast resistant hangar,

(5) Protected personnel areas,

(6) Three deluge systems and numerous sprinklers,

(7) Gas detector systems and temperature alarms,

In the case of a solid fuel launch, safety is inherently superior. Handling is similar to that customarily employed with ammunition. Ignition of rocket motors takes place off the ship and the tubes are tilted to prevent a dud from falling back.

The measures to enhance safety are taken as a normal matter of prudence. There is no reason to expect that the probability of an explosion on a ship is greater than it would be at a land launching site. In a catastrophic explosion of Cape Canaveral damage is on the order of 2.5 millions of dollars and there is no loss of life. The figures are believed to apply to the ship launch case with at least order of magnitude accuracy.

SECTION VI
PROGRAMMING

A. TASK BREAKDOWNS

A major task arises early in the program of matching the hardware and timing against the budget and operational requirements. In Figure VI-1 on the subject of Program Phasing this is listed as preliminary engineering and preliminary PERT. There are a number of essential technical studies which must be carried beyond the level of effort and thoroughness that is found in the feasibility investigations, e.g., the preferred guidance and control subsystems and adaptations as required to match the ship mounted items of support equipment, also the range of motions and weight capacity to go into a stabilized platform as part of a launcher for liquid fuel boosters. As a part of this phase contract plans are marked up for the ship conversions. Maximum use must be made of PERT techniques to predict the time scale for the various options and also the critical paths.

Contractor selection involves evaluation of the technical merit in their response to the invitation. Also there will be evaluation of general competence in past contracts as to technical proficiency and ability to complete work at this magnitude on time.

Referring again to the figure, the major laboratory and contractor tasks are itemized. Concurrently with ship conversion there will be a test program to uncover operational problems with the selected

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PROGRAM PHASING

1. PRELIMINARY ENGINEERING AND PRELIMINARY PERT
2. CONTRACTOR SELECTION
3. INITIATION OF PERT AND MAJOR TASKS SUCH AS:
   - A. SHIP CONVERSIONS
   - B. SHIP LAUNCH TESTS
   - C. MANUFACTURE AND TEST INSTRUMENTATION
   - D. ORDER BOOSTER COMPONENTS AND ADAPTERS
   - E. INSTALL AND TEST EACH SUB-SYSTEM
   - F. TEST OF SYSTEM
   - G. FIRE LIVE SHOTS

launcher. Subsystem tests and mechanical compatability checks are included to provide maximum assurance of system operability at the time of integrating them with the ship.

B. TIME SCALES AND COSTS

In the summary chart (Figure VI-2 and VI-3) there are estimates of ship conversion costs and time for completion. For the existing and fully developed launch vehicles, the ship conversion time governs the availability of the system. The range is one to one and one-half years for a minimum conversion and three to four years for the completely equipped and hardened hulls. The spread in both those estimates shows the gain that could be made by assigning high priority to the job ("crash program" status) and also effective management.

The spectrum of costs is shown for the degree of conversion. Five categories range from approximately 20 millions to 100 millions. The least expensive conversion would use a C-3 hull with the fewest structural modifications to install a launcher for Thor. Maximum use would be made of existing ground support equipment which alread has a high degree of mobility. The capacity for launch vehicles is minimum; two Thor with Agena-B upper stage would be the limit. At about the same time and cost levels, a conversion for cold launch of solid fuel vehicles would increase the capacity to four.

At the high end of the cost-time scale are the hardened Mariner AGSL and the combatant hull. Support electronics would be most appropriate to the ship environment, maintenance provisions would be best, handling and checkout facilities would result in the shortest "reaction time" to a launch order, and safety provisions are most elaborate. In

SUMMARY EXISTING VEHICLES

MAXIMUM GROSS PAYLOAD LBS.			1000 - 1500	2000 - 2500	7000 - 8000
VEHICLES			THOR-ABLESTAR	THOR-AGENA B	ATLAS-AGENA B
GUIDANCE					
CHANGE IN ORBIT ERROR					
LEAD TIME					
CONVERSION TYPE	CONVERSION COST MIL $	YEARS			
C3 HULL MINIMUM CONVERSION 2 THOR-ABLESTAR OR 1 ATLAS-AGENA B OR POLARIS	20-30	1-1½			
C3 HULL SEMI-HARDENED 3 OR 4 THOR-ABLESTAR OR 2 OR 3 ATLAS-AGENA B	30-40	1½-2			
C3 HULL SEMI-HARDENED 10-12 MINUTEMEN OR 10-16 POLARIS	40-60	2-3			
MARINER HULL FULLY HARDENED COMPLETELY EQUIPPED 3 ATLAS-CENTAUR OR 4 ATLAS-AGENA B OR 20 SOLID-TYPE	60-85	3-4			
COMBATANT HULL FULLY HARDENED COMPLETELY EQUIPPED 6-8 ATLAS-AGENA B PLUS A FEW SOLID-TYPE	85 MIN.	3-4			

SUMMARY FUTURE VEHICLES

MAXIMUM GROSS PAYLOAD LBS.			500-1000	1000-2000	2000-4000	4000-8000	8000 & OVE[R]
VEHICLES			POLARIS	MINUTEMAN	ATLAS TITAN I	TITAN II	ATLAS-CENTAU[R] TITAN II-CEN[TAUR]
GUIDANCE							
CHANGE IN ORBIT ERROR							
LEAD TIME							
CONVERSION TYPE	CONVERSION COST MIL $	YEARS					
C3 HULL MINIMUM CONVERSION 2 THOR-ABLESTAR OR 1 ATLAS-AGENA B OR 4 POLARIS	20-30	1-1½					
C3 HULL SEMI-HARDENED 3 OR 4 THOR-ABLESTAR OR 2 OR 3 ATLAS-AGENA B	30-40	1½-2					
C3 HULL SEMI-HARDENED 10-12 MINUTEMEN OR 10-16 POLARIS	40-60	2-3					
MARINER HULL FULLY HARDENED COMPLETELY EQUIPPED 3 ATLAS-CENTAUR OR 4 ATLAS-AGENA B OR 20 SOLID-TYPE	60-85	3-4					
COMBATANT HULL FULLY HARDENED COMPLETELY EQUIPPED 6-8 ATLAS-AGENA B PLUS A FEW SOLID-TYPE	85 MIN.	3-4					

short, this kind of conversion gives maximum assurance of a successful accomplishment of the mission.

In using Figures VI-2 and VI-3, for both present and future launch vehicles, it will be apparent that the row-column intersections of the upper right and lower left regions are the most appropriate ones. The larger sized launch vehicles would not find adequate space on the C-3 conversion for expeditions handling, checkout, and erection. Conversely, for the solid fuel vehicles and for Thor, the greater space of the Mariner or a combatant hull is not essential.

SECTION VII
FEASIBILITY

A. REVIEW OF OPERATIONS PERFORMED AT SEA

In Figure VII-1 there appears an abbreviated indication showing that all the subtasks of sea launch operations are within the state-of-the-art. Taken all together these produce the capability to perform the mission. Consider them in more detail (numbers match those of the figure):

(1) Ships operate at will in all seas and under adverse weather conditions. Naval ships are high speed units. Hulls are available for conversion. All support facilities, both base and mobile, exist and are available, including shipyards, supply and ammunition depots, depot and repair ships, and command ships.

(2) Resupply and replenishment at sea is a well-practiced art vastly multiplying the endurance of naval unit. Fuel and all types of small stores are transferred. High line operations have been applied to 6,000 lb. articles.

(3) Instrumentation of ships is advanced to a degree comparable to land installations. Range ships at both AMR and PMR and the Advent/Syncom ship are capable of all functions including command and control. Naval communications are world-wide in scope.

OPERABILITY

	OPERATION	DEMONSTRATED	
1	SHIPS AND SUPPORTING EQUIPMENT	YES	
2	RESUPPLY AND REPLENISHMENT AT SEA	YES	
3	INSTRUMENTATION, TELEMETRY COMMAND, COMMUNICATIONS	YES	
4	PRECISE NAVIGATION AND STABLE PLATFORMS - SINS	YES	
5	FUEL HANDLING AT SEA - HYDROCARBON AND CRYOGENIC	YES	
6	BOOSTER CHECKOUT AT SEA	YES	
7	BOOSTER RELIABILITY (OFF-THE-SHELF)	YES	
8	TUBE FIRING AT SEA (SOLIDS)	YES	
9	ERECTION AND FIRING AT SEA (LIQUID)	YES	
10	SHIP CONTROL AND INJECTION OF ORBITING PAYLOADS	YES	
11	ERECTION AND FIRING AT SEA OF VERY LARGE VEHICLES		NO

(4) The most advanced components available from the inertial instrumentation art are employed in SINS. This type of system has been employed to navigate submarines under the polar ice cap. Multiple systems are employed in ships each having different error characteristics yielding the minimum possible net error. Transit equipment is progressing to operational status and will be available for sea launches.

(5) Fuel handling at sea is a routine practice since aircraft carriers have been using immeasurably large quantities of high octane gasoline. Various other liquids, inflammable and toxic, have been handled including cryogenic propellants.

(6) Numerous missiles and rockets have been taken to sea, handled with mechanized equipment in various degrees of development and checked out for operability prior to launch: V-2, Aerobee, Viking, Regulus, Terrier, Talos, Tartar, and Polaris.

(7) The launch vehicles to be employed in this mission are fully developed both as to reliability, compatibility with orbiting payloads, and compatible with the launch environment. For example, the Thor system; highly mobile, has been air transported and emplaced at overseas bases.

(8) Tube firing at sea was first performed from a surface ship; U.S.S. Observation Island. The Polaris system is operational.

(9) Missiles and rockets have required erection and launching on the deck of a ship. These have included Aerobee, Argus, V-2,

and Viking. The latter two employed liquid fuel and at the time of their launch were regarded as large vehicles.

(10) In connection with range operations, instrumented ships have tracked and commanded flight vehicles as part of the sequence into orbit. The critical signal for orbital injection are transmitted from ships as part of routine launching operations at PMR.

(11) At the present time the category of very large flight vehicles consists mainly of Atlas with an Agena-B upper stage. This booster has not been fired at sea at the time of this writing.

B. RELIABILITY AND MAINTAINABILITY

Reliability estimates in simplified form are shown in the table (Figure VII-2) for both a land based system and ship based system. The ranking for the various subsystems are in line with those coming out of detailed analyses for satellite programs which emphasize reliability.

The distinction between a land based system and a sea launch using the same launch vehicle is seen to be slight. The basis on which similar figures are estimated for the two cases is that the checkout equipment for the ship system is equally capable of detecting a defective or marginal subsystem as is the land checkout. Less information would be available to track down the defect. A simple "go" indication is preferred. The checkout equipment and other essential ground support items would have most effect on over-all system reliability due to the sheer quantity of components involved and a small advantage is given to the land system.

RELIABILITY & MAINTAINABILITY

PROBABILITY OF SUCCESS		LAND BASED	SEA LAUNCH
PROPULSION	LIQUID	* * *	* * *
	SOLID	* * * *	* * * *
GUIDANCE AND CONTROL, ETC		* * *	* * *
PAYLOAD		* * *	* * *
GROUND ELECTRONICS		* *	*
OTHER GROUND SUPPORT, FUELING		* * *	* * *

MAINTENANCE COMPARISON	LAND BASED	SEA LAUNCH
PRELAUNCH ENVIRONMENTAL CONDITIONING	YES	YES
REPAIR BY MODULE REPLACEMENT	YES	SOME
SUBSTITUTE PROPULSION STAGES, PAYLOAD	YES	YES
EMPHASIS ON PREDELIVERY SERVICE	SOME	YES
FINAL CHECKOUT DETECTS DEFECTS	YES	YES
FREQUENT MAINTENANCE OF CHECKOUT EQUIPMENT	YES	YES

The ship system would ride for long periods in a motion environment and require more frequent maintenance which is not conducive to highest reliability.

With regard to the launch vehicle and payload the maintenance concept contains two obvious differences. Flight articles are given intensive checkouts prior to acceptance for delivery to the ship and the burden on the contractor to produce a reliable product is maximum. Following acceptance and delivery to the ship there is less maintenance and only a designated group of packages and modules may be replaced where accessability is present and where the replacement does not require intricate adjustments. Actually this is only a full exploitation of an already established trend where weapons and other equipment proceed from a developmental to an operational status. Substitution at complete propulsion stages and payloads is also possible. Environmental conditioning is part of the maintenance concept and the flight vehicles get a conditioned atmosphere and anti-vibration mounting.

C. FEASIBILITY ASSESSMENT

To reach a final feasibility assessment of sea launch these questions will be considered:

(1) Are all the subtasks associated with ship launch contained in the demonstrated operations both as to kind and degree of difficulty?

(2) Are reliability and maintainability of at least the order of magnitude level as land-based launch operations?

(3) Are guidance and control capable of producing satisfactory orbits?

The answers are all affirmative. In assessing the feasibility it is rather pointless to attempt a numerical percentile rating. No subtasks have been uncovered which qualify the affirmative answers. The fuels which have been handled are as difficult as those which must be handled. Many of the components being used in land based systems would be employed without change. The differences in reliability at sea are not appreciably different from those on land--probably the difference one way or the other cannnot even be predicted to closer accuracy than the difference itself. In guidance and control the situation is the same-possible errors in estimating the errors are as large as the degradation in taking a control system to sea. The conclusion is: Positive feasibility.

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CONFIDENTIAL

A STUDY OF THE MOTIONS OF THE MARINER HULL AT CERTAIN SEA STATES APPLIED TO THE ATLAS CENTAUR AND ATLAS AGENA VEHICLES

Contract No. NOBS 84751

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SECURITY

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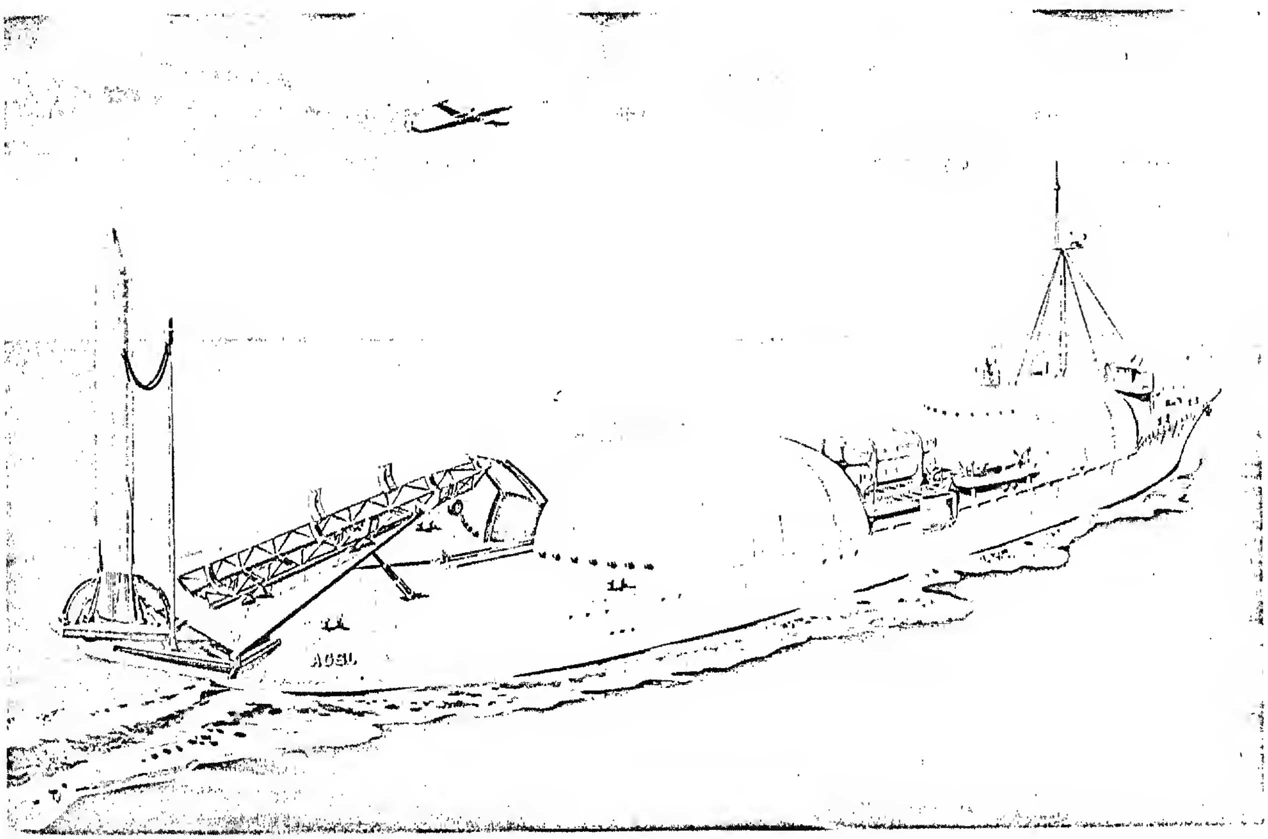
Abstract

The motions of the Mariner hull as a launching platform are applied to the Atlas/Centaur flight configuration to define the highest sea state at which the combination would be operationally feasible. By comparing the maximum design upset moment of the Atlas/Centaur vehicle with the moments induced upon it by the motion of the ship (including random waves and gusts), it is concluded that operations up to and including sea state 3 are structurally acceptable to the vehicle.

Some of the launching, handling, stowage, and blast damage caused by catastrophic failure at the pad or soon after lift-off are touched upon, indicating catastrophic failure of the vehicle as a major design problem.



Frontispiece

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PART I

INTRODUCTION AND DESCRIPTION OF PROPOSED SHIPS LAUNCHING FACILITIES AND FLIGHT CONFIGURATION CRITERIA

INTRODUCTION

This report is written under contract (Nobs 84751) to the Navy Department, Bureau of Ships as a part of their contribution to the joint Army, Navy, and Air Force Mobile Sea Launch Operations Studies. It is intended to cover the following specific assignment from the Bureau of Ships:

*1. At what sea state do structural considerations become critical for Atlas/ Agena and Atlas/Centaur ?

Consider: Transportation
Erection
Handling
Launching

*2. Define the total launching weight ratio (F/wl) required by Atlas/Agena and Atlas/Centaur for launching during the various allowable sea states.

*For both assignments:

(a) Consider Mariner class ships only.
(b) Consider launching over the stern.
(c) Consider stabilized platform, passive hydrodynamic ships stabilization system.

A. Philosophy of Ships Modification

Bureau of Ships has elected to raze all superstructure of the Mariner class vessel above the main deck and rearrange the main deck to include:

1. A hangar to provide horizontal housing of three Atlas/Centaur and/or Atlas/ Agena flight configurations (not to extend forward beyond the after boiler room bulkhead).

2. A stabilized launching pad to be installed aft of the fantail in such manner that the vehicle blast is dispersed over the stern of the vessel.

3. A system of tracks and conveyors to ensure positive control of the flight assemblies while moving them on board and, to effect selection of any one of these vehicles for firing.

4. An erector mechanism to install the selected vehicle in the vertical position on the pad for fueling, final checkout operations, and firing.

5. Provision for stowage of small boats and cryogenic propellants on topside, forward of the hangar.

6. Provision for all facilities necessary to handling functions of the ship such as anchoring facilities, dock lines, etc. on topside.

7. Rearranging the boiler uptake to exhaust at the sides of the ship.

8. A blockhouse and bridge containing adequate space for launch control and tracking functions conceived in such a manner as to resist blast in the event of an explosion of the flight configuration at the launching pad or very soon after lift-off.

This general arrangement is shown in Figure 1.

B. Description of Hangar

Three Atlas/Centaur and/or Atlas/Agena flight configurations would normally be stowed abreast, (i.e., center, port, and starboard) on a track system which provides positively controlled movement by flush type conveyors fore and aft or athwartship. Investigation of available space shows that clearances would be adequate to arrange all three vehicles on the transverse tracks in such manner that selection of any of the three for firing would be assured without the inconvenience and hazard of hoisting a unit off the restraining tracks (Figure 1).

The housing or hangar which contained these facilities would be so positioned as to permit adequate provision for the erecting function described later in this report. While the hangar (See Frontispiece) would be so shaped as to efficiently resist blast and heat resulting from malfunction explosion of the vehicle on the pad, it must be emphasized that positive survival of the structure in the event of the catastrophic explosion of the Atlas LOX/fuel complement at the pad or very soon after lift-off appears extremely doubtful.

Aerospace Corporation has instrumented a series of actual catastrophic explosions of Atlas. They are now in the process of deriving empirical equations by which over pressure intensities vs. distance from the explosion center may be calculated for any propellant combination involved. Since gage calibration is still a problem, however, certain uncertainties remain concerning the proven formula.

By the shock tube method of gage calibration, for over pressures greater than one (1) psi, the basic equation is as follows:

$$\frac{3758}{Z^3} + \frac{256}{Z^2} + \frac{41}{Z} = P$$

where $Z = \frac{R}{W^{.279}}$

R = distance in feet
W = total propellant weight in lbs.

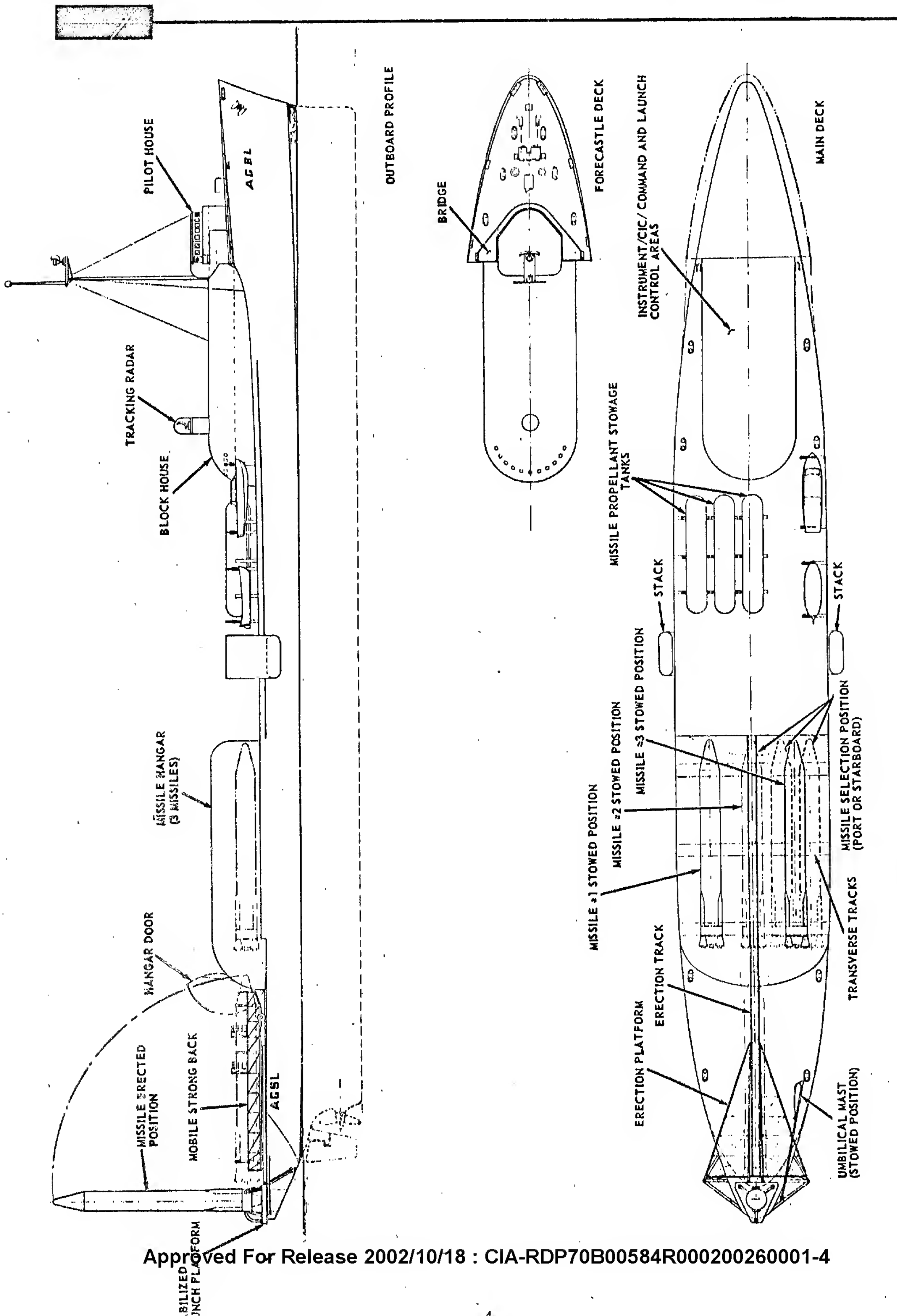

Figure 1 AGSL Mariner Outboard Profile

A later gage calibration, however, has modified the equation to:

$$\frac{3016}{Z^3} + \frac{221}{Z^2} + \frac{38.1}{Z} = P$$

where $Z = \frac{R}{W^{0.3}}$

Both curves have been plotted (Figure 2) and, it is assumed that over pressures vs. distance would be somewhere in the corridor described.

In order to resist overpressures of 96 psi (Figure 2), the structure appears to require a skin of 1.75 inches supported by I-beam arches on 30 inch centers, each of which would weigh some 8500 lbs. Total weight of the blast-proof hangar (allowing for diminishing skin gages toward the forward region of the structure) then, is estimated at 325 tons, approximately. Since the center of gravity is approximately 30 feet above the center of gravity of the ship, an overturning moment of about 9,750 ton-feet could be anticipated. Time does not permit investigation of the effect of this mass on the characteristics of C-4, however, the structure appears to be so massive as to appear economically infeasible.

Accordingly, the skin is tentatively specified as 0.25 inch plate with a suitable refractory coating and, total weight of the correspondingly reduced support structure is estimated at about 160 tons, resulting in a moment of 4,800 ton-feet. Blast overpressures of about 15 psi appear acceptable with this structure. The weight distribution of the hangar will be ignored in the following ships motion studies, the assumption being made that the new superstructure would yield about the same moment as that removed from the original ships configuration.

C. Flight Configuration Criteria

Since Atlas/Centaur configuration is longer and heavier than Atlas/Agena, it is assumed critical and the following studies are based upon the use of this vehicle. Pertinent criteria of Atlas/Centaur are shown below from the sources described (Ref: (2) TWX 7 July 1961):

(1) Bureau of Ships (2) General Dynamics Astronautics

(1) Length	105 ft.
(1) Diameter	10 ft.
(2) Mass of vehicle on launcher	9212 slugs
(2) Mass of vehicle at lift-off	9112 slugs
(2) Total thrust at lift-off	360,000 lbs.
(2) Allowable axial load at lift-off	1.5g
(2) Maximum design moment about base (launch support point)	4,000,000 lb/in.

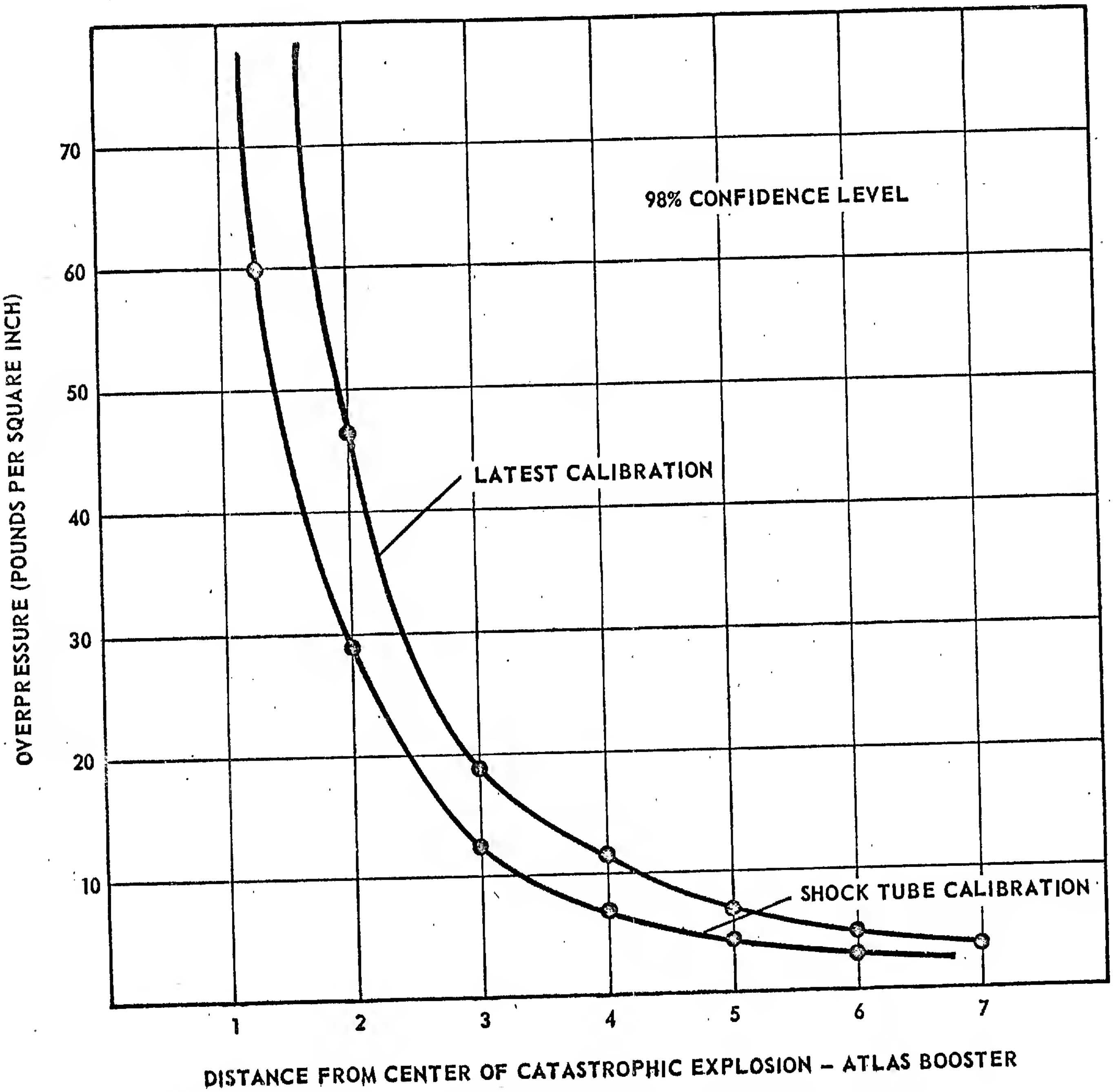

Figure 2 Overpressure vs Distance Based on Two Gage Calibrations for Atlas Tests

(2) Height of cg above launch support point	32 ft
(2) Moment of inertia about launch support point	12,580,000 slug/ft^2
(2) Moment of inertia about cg	3,150,000 slug/ft^2

Approximate weight distribution measured above launcher support point as a zero reference:

(2) 0 to 20 ft	4500 lbs/ft
(2) 20 to 52 ft	5400 lbs/ft
(2) 52 ft to 65 ft	41 lbs/ft
(2) 65 ft	23,500 lbs/concentrated
(2) 65 ft to 81 ft	406 lbs/ft
(2) 85 ft	1200 lbs/concentrated
(2) 87 ft	1000 lbs/concentrated

D. Launching, Stowage, and Handling Philosophy

Since the Atlas/Centaur/Agena flight configurations are extremely sensitive to bending, a mobile strongback providing rigid support over the full length of the configuration is indicated for all stowage, handling, and checkout functions to be performed with the vehicle in the horizontal attitude.

The three vehicles would be loaded on board, fully assembled, from dock side. The vehicle/strongback assembly would be lowered into tracks extending from the after deck by a dock-side crane, made fast to a flush deck conveyor and transferred forward, inside the hangar. A further transfer operation by an athwartship conveyor would move them to their respective stowage positions where they would be secured. Thus, positive ship board control of the strongback dolly would be achieved at all times.

Major checkout functions would be executed with the vehicle in the horizontal attitude on the strongback and, inside the hangar space.

After major checkout, the empty vehicle would be transferred outside the hangar by conveyor to the erecting position on the after deck. Erection would be accomplished by fixing an erector frame to the strongback, the whole actuated to the vertical position by means of telescoping hydraulic rams. The umbilical mast would be erected independently and, simultaneously. When erected, the vehicle restraining feature of the strongback would double as work staging for final checkout and fueling operations. After fueling and final checkout, the vehicle, independently supported and restrained upon the stabilized launching platform, would be disengaged from the strongback erecting frame assembly which would retract to the deck. The strongback would then be disengaged from the erecting frame and transferred back into its permanent stowage position in the hangar.

The umbilical mast would remain in position until main stage ignition, at which time all connections would be quickly disengaged and the mast pivoted to stowage alongside the rail by conventional methods.

It appears that a modification to the conventional Atlas launching support scheme would be mandatory for shipboard launching missions, probably leading to the modification of Atlas in the pad support region of the flight structure about eight feet above the base.

E. Mobile Strongback Description

This component would consist of a welded steel framework with a suitable suspension system mounted on high pressure rubber-tired castors. Service platform sections would serve also as restraining members for the flight configuration. The combined weight of the empty missile and the strongback is estimated at 50,000 lbs.

F. Erection Equipment Description

This system would consist of an erecting platform and an actuating system.

The erecting platform of welded steel construction is in the configuration of a semi-"A" frame, owing to the desire for transverse stability. It is shown pivoted in tapered bearings at the base, (See Frontispiece) supported by outriggers extending port and starboard from the stern of the ship. The platform would be positively fixed by tapered shank bolts or other suitable means to the strongback, resulting in a rigid integral structure to contain the flight vehicle and restrain it vertically during fueling and final checkout.

G. Hydraulic System Description

The actuating force for the erecting sequence would be supplied by two (2) twelve inch hydraulic cylinders, each containing four (4) fourteen foot telescoping sections (incorporated in a 15 foot housing) for a total extended length of 71 feet. The hydraulic system would contain the necessary controls, accumulators, etc., to ensure constant, surge-free erection and lowering by a servo valve. The system would be designed "fail-safe" and remain locked in position until hydraulic energy is again supplied from the pump.

One hundred twenty-five (125) horsepower delivered to the pump appears adequate to erect the combined weight of the empty flight vehicle, strongback, and erecting platform which is estimated at 75,000 lbs. The center of gravity of the assembly to be lifted appears to be about 50 feet from the fulcrum point. The total erection time is assumed at two minutes.

The launcher table is stabilized by servos, essentially damping pitch and roll misalignments. The relationship of these motions of the ship to a stable platform reference would provide actuation signals to the servos.

H. Retraction and Launch Sequence

After fueling and performing the remaining checkout functions, hydraulically actuated hold-down arms clamp the missile to the supports or "tippers" applying essentially the same principles as the conventional Atlas launching gear but, utilizing a greater number of the combination suitably spaced for the requirements peculiar to the sea launch mission. It is again pointed out that the ship board requirement may well necessitate a completely new design concept for restraining the missile to the launching support.

With the vehicle secured to the launch pad, the empty strongback is disengaged from the vehicle and lowered to the deck by the erecting platform. The strongback is then released and transferred to the hangar. A salt water deluge is then applied to the after deck of the ship immediately prior to ignition from nozzles mounted in the base of the hangar.

The exhaust blast from the vehicle engine is deflected outboard, astern, and downward by refractory-lined deflectors.

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PART II

MOTION STUDIES OF THE MARINER HULL AS APPLIED TO THE ATLAS CENTAUR VEHICLE DURING CERTAIN SEA STATES

A. Derivation of Force and Moment Equations

The forces and moments acting upon the missile as a result of ship motion can be found by assuming a 3 degree-of-freedom (pitch, roll, heave) mathematical model of the ship. Additional assumptions required are:

1. The motion of the ship in pitch, roll, and heave is sinusoidal and the angles in pitch and roll are small.
2. The effect of cross coupling between pitch and roll planes is negligible.
3. The missile is supported only at its base and is perpendicular to the ship's deck.

The motion of the ship is defined by a pitch equation

$$\phi_s = \Phi \cos \omega t \tag{1}$$

and a heave equation

$$y_s = Y \cos (\omega t + \epsilon). \tag{2}$$

The motion of the missile's c.g. as a function of the ship's motion is written by inspection (see Figure 3):

$$\phi = \phi_s \tag{3}$$

$$y = y_s + A \cos \phi - B \sin \phi \tag{4}$$

$$x = - A \sin \phi - B \cos \phi. \tag{5}$$

Referring to Figure 1, the equations of motion can be written by a summation of forces and moments. In the horizontal direction,

$$m\ddot{x} = F \sin \phi + V \cos \phi \tag{6}$$

in the vertical direction,

$$m\ddot{y} = F \cos \phi + V \sin \phi - mg \tag{7}$$

and summing moments about the missile's c.g.,

$$I\ddot{\phi} = Vb + M. \tag{8}$$

PART III

CONCLUSIONS AND RECOMMENDATIONS

Conclusions and Recommendations

Assignment #1

At what sea state do structural considerations become critical to Atlas/Centaur Atlas/Agena flight configurations? Consider:

Transportation

Erection

Handling

Launching

In the matter of transportation, erection, and handling of the vehicle, it is our conclusion that a judicious system design which ensures positive control of the unit at all times, with adequate safety-locking device and, which does not require that the unit be hoisted or removed from these restraints is quite feasible, and presents no overly difficult problems at any reasonable sea state. These operations, in other words, would not be critical in the overall operation and would impose no undue stresses upon the flight configuration.

The launching phase becomes the critical problem. In compiling Tables I through IV, certain assumptions were made which should be emphasized here.

1. We have used Atlas/Centaur as the model in all motion studies, since this configuration is longer and heavier than Atlas/Agena and we have considered it critical.

2. All motion studies refer to the Mariner (C-4) hull.

3. All computations concerning the flight configuration have assumed a rigid vehicle and have given deflection in bending no consideration. For this reason, the results are somewhat optimistic for the flight configuration.

4. Launching would always be effected with the ship heading into meeting seas at a velocity of 6 KTS.

5. All computations have been made assuming the vehicle is fixed to a permanent platform and, that neither the ship nor the platform is stabilized.

Many factors are involved in the identification of the operational sea state. In the first place, the seas are not so cooperative as to maintain constant wave heights, directional consistency, constant winds, etc. In the final recommendation we must consider random waves approaching from a critical direction and groups of waves followed by smooth seas followed in turn by other groups of waves. We must also consider gusts. These phenomena are significant to the motion of the ship and to the implied moment imparted to Atlas/Centaur. Should they occur during what we define as a given sea state, they may well induce a considerably more severe reaction of the hull to the seas than that imparted by action of the regular sea state. For this reason, after defining the reactions of the ship with respect to the maximum design

upset moment of 4,000,000 inch-lbs at the Atlas pad restraining point, we recommend the various stabilizing devices be considered as safety measures only, to damp the results of combined random gust and wave reactions to the vehicle. We believe consideration of the stabilizing devices in this sense will result in a more realistic approach to the operational problem.

6. Table IV shows that sea state 4 induces a combined moment to the Atlas at the launch support point of 10,400,000 inch-lbs. in the roll plane (in the trough) and, 4,300,000 inch-lbs. in the pitch plane (heading into meeting seas). By the above reasoning, then, to launch Atlas at sea state 4 (the ship heading in to meeting seas) failure of the vehicle on the pad in the launching support region of the flight structure is indicated in the pitch plane.

7. Sea state 3, on the other hand, appears to apply no critical base moment to the flight configuration as long as the ship heads into meeting seas for the launching function.

Therefore, it is our studied opinion that sea state 4 is that at which structural considerations become critical to Atlas/Centaur and that launching should be attempted in sea states no greater than 3.

Assignment #2

Define the total launching weight ratio (F/W_L) required by Atlas/Agena and Atlas/Centaur for launching during the various allowable sea states.

1. F/W_L for Atlas/Centaur (from Criteria in Part I)

W_L = mass of vehicle at lift-off x g =
= 9112 x 32.2
= 293, 406.4 #

F = thrust at lift-off = 360,000 #

$$F/W_L = \frac{360,000}{293,406.4} = \underline{1.225}\ (g)$$

2. In Assignment #1, it was concluded that launching must be limited to state 3 seas. The maximum vertical acceleration of the launch deck in this sea state is expected to be 1.025 g (refer to section on "Deck Accelerations").

3. Therefore, it is our opinion that a large safety span exists concerning the deck acceleration in sea state 3 and, that launching Atlas/Centaur with respect to heave of the C-4 hull may be accomplished with confidence without the synchronization of lift-off to ships heave motion.

In conclusion, it is to be emphasized that Atlas/Centaur was designed for maximum performance. The price paid for this flight efficiency emerges in the complexity of the system; the reliability record of the configuration; the hazardous propellants to be transported, stowed, and handled; and the sensitivity of the

structure to motion of its launching pad with respect to the shipboard environment. This price has proved acceptable for tactical and R & D utilization of the vehicle in the land environment for which it was intended when weighed against improved performance.

This report concludes that launching of Atlas/Centaur is feasible in state 3 seas from the stern of the Mariner vessel with regard to the environmental structural loads imposed upon it. It does not presume to judge all of the factors incident to its overall feasibility as an R & D vehicle in the shipboard environment since, such judgment would be premature and unfair in the absence of a considerably more comprehensive investigation.

Nomenclature

A, B, C	Vertical, longitudinal, and lateral distances from missile's c.g. to ship's c.g., respectively, feet.
b	Longitudinal distance from missile's c.g. to plane in which missile is supported, feet.
B_1	Beam of ship, feet.
C_D	Aerodynamic drag coefficient.
D	Base diameter of missile, feet.
F	Axial force at the base of the missile, lbs.
g	Acceleration of gravity (32.2 ft/sec^2).
H	Wave height, crest to trough (2 × wave amplitude), feet.
I	Moment of inertia of missile about its c.g. in pitch or yaw (excluding mass of missile below support), $slug\text{-}ft^2$.
L	Water line length of ship, feet.
L_e	Effective aerodynamic length of missile from support, feet.
m	Mass of missile above plane of support, slugs.
M	Moment at the supporting plane of the missile, foot-lbs (unless otherwise specified).
M_p	Moment resulting from ship motion in the pitch plane, foot-lbs (unless otherwise specified).
M_{pl}	Base moment due to pitch at wave encounter frequency.
M_{pp}	Base moment due to pitch at resonance frequency.
M_{pt}	Total maximum pitch moment, $M_w + M_p$ (sum).
M_r	Moment resulting from ship motion in the roll plane, foot-lbs (unless otherwise specified).
M_{rt}	Total maximum roll moment, $M_w + M_r$ (sum).
M_w	Base moment due to wind.
N	Aerodynamic normal force on missile, lbs.
t	Time, seconds.
T	Natural or resonant roll period (16.5 secs).
T_1	Wave period. Also period of wave encounter in pitch, secs.